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A Framework for Profiling based on Music and Physiological State

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To my dear Cheila and my family

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Abstract

The IoT (Internet of Things) is an emergent technological area with distinct challenges, which has been addressed by the world research community. This dissertation proposes the use of a knowledge-based framework capable of supporting the representation and handling of devices along with some autonomous interaction with the human being, for creating added value and opportunities in IoT. With usability in mind, the objective lays in an attempt to characterize users' physiological status mainly through music in a profiling approach. The idea is to produce a solution able to customize the environment by musical suggestions to the actual scenarios or mood that the users lie in. Such system can be trained to understand different physiological data to then infer musical suggestions to the users. One of the adopted methods in this work explores that thought, on whether the usage of a person's physiological state can wield adequate sensorial stimulation to be usefully used thereafter. Another question considered in this work is whether it is possible to use such collected data to build user's musical playlists and profile that tries to use the user's physiological state to predict his or her emotional state with the objective to reach a well-being situation.

Keywords: data analysis, musical recommendation, Ontologies, Knowledge Representation, physiological states

Resumo

O IoT (Internet of Things) é uma área tecnológica emergente com desafios distintos, que tem sido utilizada pela comunidade mundial de investigação. Esta dissertação propõe o uso de uma base de conhecimento capaz de suportar a representação e a manipulação de dispositivos com alguma interação autónoma com o ser humano, para criar um valor acrescentado e oportunidades no IoT. Com o propósito da usabilidade, o objetivo reside na tentativa de caracterizar o estado fisiológico dos utilizadores através de uma abordagem de perfil. A ideia é produzir uma solução capaz de personalizar o ambiente através de sugestões musicais para o cenário atual ou humor em que o utilizador se encontra. Este sistema pode ser treinado para entender diferente informação fisiológica para, posteriormente, inferir sugestões musicais aos utilizadores. Um dos métodos adotados neste trabalho explora esta vertente, se o uso do estado fisiológico de uma pessoa pode exercer uma estimulação sensorial adequada para ser, subsequentemente, utilizada de forma útil. Outra questão considerada neste trabalho é a possibilidade de se utilizar os dados recolhidos para criar uma lista de música pessoal do utilizador e um perfil que tenta prever o estado emocional do(a) utilizador(a) com base no seu estado fisiológico com o objetivo de se alcançar uma situação de bem-estar.

Keywords: análise de dados, recomendação de músicas, Ontologias, Representação de Conhecimento, estados fisiológicos

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Acronyms

AIS Artificial Intelligence System

ANOVA Analysis of Variance

ANS Automatic Nervous System

ASCII American Standard Code for Information Interchange

BPM Beat Per Minute

BVP Blood Volume Pulse

ECG Electrocardiogram

EEG Electroencephalogram

EHR Electronic Health Records

EMG Electromyogram

FP Fisher projection

FP7 7th Framework programme

GA Genetic Algorithm

GSR Galvanic Skin Response

HF High Frequency

HL7 - Health Level Seven

HR Heart Rate

HRV Heart Rate variability

HUD head-up display

I2C Inter-Integrated Circuit

IBI Interbeat Interval

ICT Information Technology and Communications

IHE Integrating the Healthcare Enterprise

IoT Internet of Things

JDBC Java Database Connectivity

LF Low Frequency

MAP Maximum a Posteriori

OCC Ortony, Clore and Collins

OWL Web Ontology Language

PSD Power Spectral Density

RDF Resource Description Framework

RDFS Resource Description Framework Schema

RFID Radio Frequency Identification

RMSSD Root Mean Square of the Successive Differences

SD Standard Deviation

SFFS Sequential floating forward search

SPO2 Peripheral Capillary Oxygen Saturation

SQL Structured Query Language

SVM Support Vector Machine

URI Uniform Resource Identifier

VLF Very Low Frequency

W3C World Wide Web Consortium

XML Extensible Markup Language

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1. Introduction

Technology is being used to improve citizen's daily life. Through the creation and improvement of new technologies, the comfort of people is becoming better every day. This technological progress has made possible to extend the use of Information Technology and Communications (ICT) to new applications to improve our quality of life. The ICT intends to make systems more intelligent, more energy-efficient and more comfortable in order to make the citizens a better use of cities' resources. One example of this tendency is IoT, which increases intelligence of the objects around us and connects them to the network to exchange data without requiring human interaction, because everything is connected and connected to the network. With the increase of sensors around us, it is possible to acquire useful physiological and psychological information about each person and data about the surrounding environment. This huge amount of personal information can be useful to create new systems with the purpose of improving user's wellbeing using, for instance, musical stimulus. Music is present is many public places we go. Trains, buses, elevators, restaurants or hospitals are some public areas that uses music as background music. And if it was possible to define that music according to the majority of the emotional state of the users of these spaces? Could this simple change make the citizens happier? On [1] it was concluded that using music in a Smart Space had influence on reducing blood pressure, increased respiration (suggesting physiological responses to perception and enjoyment of music) and lowest mean of electroencephalogram (suggesting the physiologically important aspects of appealing music therapy during relaxation). Also experimental studies [2] showed that listening to positive music, when they try to improve their mood, was an effective way of improving happiness, experiencing greater gains in well-being, as measured by positive affect, subjective happiness and life satisfaction. Music is also used for an individual use. Many people listens, individually, to music while traveling, waiting or studying. It could be useful to choose music according to the current feeling state of the user, instead of a random selection. With the advance of technology and network communications, the use of mobile phones for listening music are increasing every day. In order to induce the correct stimulus on each person, it is necessary to define individual profiles because the same music can have different reactions on different users.

The integration of using music in our life result in one framework which has the objective of selecting the most appropriate music accordingly to user's emotional state and user's musical preferences. In order to have one system capable of differentiate user's physiological state is by understanding what physiological responses each user has while experiencing different emotions. An example of that is one person's heart rate (HR) increase while he/she is experiencing a stressful moment, while in a relaxing moment the opposite behaviour can be identified. This work will focus on emotional changes that users have while listening to specific music defined by themselves. This fact is important because for one person one music can make him/her feel relax while the same music to other person can make him/her feel happy. With this knowledge, it is possible to express all relations between musical information and user emotional state, through their profile, in order to provide music recommendation according to each person's physiological state and personal tastes.

1.1. Research Method

The research method used to develop this dissertation was based on Classical Method as proposed in [3]. This method is composed by seven steps, which are:

- Research question/Problem: It identifies the problem and defines the research question. This question must be capable of being confirmed or refuted. This research question is defined in section 1.1.1;

- Background/Observation: It describes previous work, in the topic made by other researchers that are necessary to understand the matter, before starting developing one possible solution for the research question. It is important to take into account the reliability of scientific documents, since their age, reliability and low experimentation can influence their scientific impact. This step is presented in section 2;
- Formulate Hypothesis: In this step, the researcher identifies the results that he is expecting to acquire. The hypothesis of this dissertation is presented in section 1.1.2;
- Design Experiment: It describes an architecture or solution prototype for experimental testing and implementation. This proposed solution should be clearly enough described to allow other researchers to repeat the experiment. This design is described in sections 3 and 4 of this document;
- Test hypothesis/Collect data: The researcher tests the presented system architecture or solution by executing their experiments. These experiments will generate data that will be analysed on next step. This step is presented in sub-sub-section 5.2.2.1.1;
- Interpret/Analyse results: From the data acquired in the last step, the researcher needs to evaluate and analyse the obtained results. With these results, he can verify if the hypothesis that he presented above can be considered as valid or not. If the hypothesis is true, the researcher can make recommendations for further research. If the hypothesis is wrong, he can improve the initial approach in order to get different results. This interpretations are presented in sub-sub-section 5.2.2.1.1.5;
- Publish Findings: If the researcher got results which prove that its hypothesis was right, he must publishing his findings in order to contribute to the scientific community. The publications are referenced in section 5.3.

1.1.1. Research Question

Can a technological solution be capable of identifying users' emotion signs patterns, supported by music profiles definition, for further wellbeing state establishment?

1.1.2. Hypothesis

If a Knowledge-based framework, that integrates devices like sensors with particular analytics algorithms, in order to identify specific users' physiological signs patterns is defined, then the establishment of personal music profiles associated to users' emotions is facilitated.

1.1.3. Dissertation Outline

This dissertation is divided in 7 sections, which are presented in the following:

- Section 1 – Introduction: It is described the purpose of this dissertation as well as the motivation behind this research project. It also reveals the adopted research method that was chosen. Finally, it is presented the research question that motivated this dissertation and its hypothesis, in order to solve that question;
- Section 2 – State of the Art: This section is used to present the state of the Art of this dissertation. It represents the information that was necessary to have in order to build one system capable of validate the defined hypothesis. To do that, first, it is presented several important aspects of Emotions. Next, it is described several physiological sensors that are used to identify changes in different emotions felt by each use. After that, it is shown the importance of music for our well-being. Finally, it is described how to build one system, using semantic, for the development of the solving methodology;
- Section 3 – Methodology: This section describes one methodology that was developed in order to solve the research question proposed above. It also has a description of one test with several sensors, used on different subjects, which is useful for the purpose of this dissertation;

- Section 4 – Implementation: This practical chapter is used to present to the reader the implementation of a prototype to prove the proposed hypothesis;
- Section 5 – Use Cases and Analysis of Results: In this chapter it is defined three different use cases, which can be used with the developed system made for this dissertation. This chapter also describes the applications already made with the developed system for the scientific community;
- Section 6 – Conclusion: The dissertation is finalized by presenting the final thoughts and remarks as well as the presented hypothesis for solving of the research question and problems identified previously. This chapter finish with a proposition for possible future work;
- Section 7 – Annexes: This section has the images used on experiment 1 as well as two different operational guides.

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2. State of the Art

This chapter provides a theoretical overview of important concepts on how to make a user's profile, using music information, to help each individual to feel better. In order to do that, first it is necessary to differentiate emotions and how they can be represented. Second, there will be presented some sensors that are used in emotional deduction as well as the importance of music in our society. The last sub-section of this chapter intends to demonstrate the importance of knowledge representation to this dissertation.

2.1. Emotions

2.1.1. Core Affect, Mood and Emotion

In order to understand the emotion it is necessary to define the similar definition of affective domain by differentiate emotion, mood and core affect. Since these definitions are very similar many researchers tend to do an individualistic approach of this definitions.

Core Affect – is a neurophysiological state that is consciously accessible as a simple *feeling*. Some examples are feeling good or bad, pleasure and displeasure, tension and relaxation, energy and tiredness. Core affective feelings vary in intensity and everybody is always in some state of core affect, even if neutral [4]. In this matter, Russell and Barrett deduced that core affect and these feelings are part of moods and emotions. This deduction is based on the presence of these feelings in moods and emotions.

Mood – is subtler, lasts longer, is less intensive and endures over longer timescales. The mood only exists through the interaction between people [5]. There is a connection between mood and emotion. For instance, when a person has a negative effect (e.g. anger), that person also tends to have elevated levels of negative moods, like fear, sadness and/or guilt.

Emotion – According to Russel and Barrett [4] they defined emotion as a complex set of interrelated sub-events concerned with a certain object, such as a person, an event, a thing, real or imagined that could have happened in past, can happen in present or will happen in future. Kleinginna and Kleinginna [6], after reviewing different definitions of emotions, compiled a list of more than 100 definitions of emotion and proposed a working definition: Emotion is a complex set of interactions among subjective and objective factors, mediated by neural/hormonal systems, which can (a) give rise to affective experiences such as feelings of arousal and pleasure/displeasure; (b) generate cognitive processes such as emotionally relevant perceptual effects, appraisals, labelling processes; (c) activate widespread physiological adjustments to the arousing conditions; and (d) lead to behaviour that is often, but not always, expressive, goal directed, and adaptive. They concluded that psychologists couldn't agree on many distinguishing characteristics of emotions.

There are six perspectives of Emotions. They can be as:

- Expressions, mostly using facial expressions where is analysed the facial expression of a person. This method is the most explored of affect's detection. It can also be analysed through voice by analysing what is said and how it is said;
- Embodiments, through physiological signals using sensors and relate this data to emotions by analysing the results and assign a correspondent emotion. The heart-beat is one example of this physiological data;
- Cognitive approaches, relating emotions to events or objects. The body language and posture is one type of cognitive approache using the relation of emotions and human body positions and gestures.

Another example is the text analysis because a written text express the user's emotion;

- Social construct, by the use of social analysis where it can be use users' behavioural data or interaction with devices and asking the user how is he/she feeling and give a set of variables to choose;
- Neuroscience, relating neurological process to emotions using, for example, through brain images that are detected by neurological circuits and mapping the affective-states;
- Psychological construct, using emotional theories to appoint the correct emotion [7].

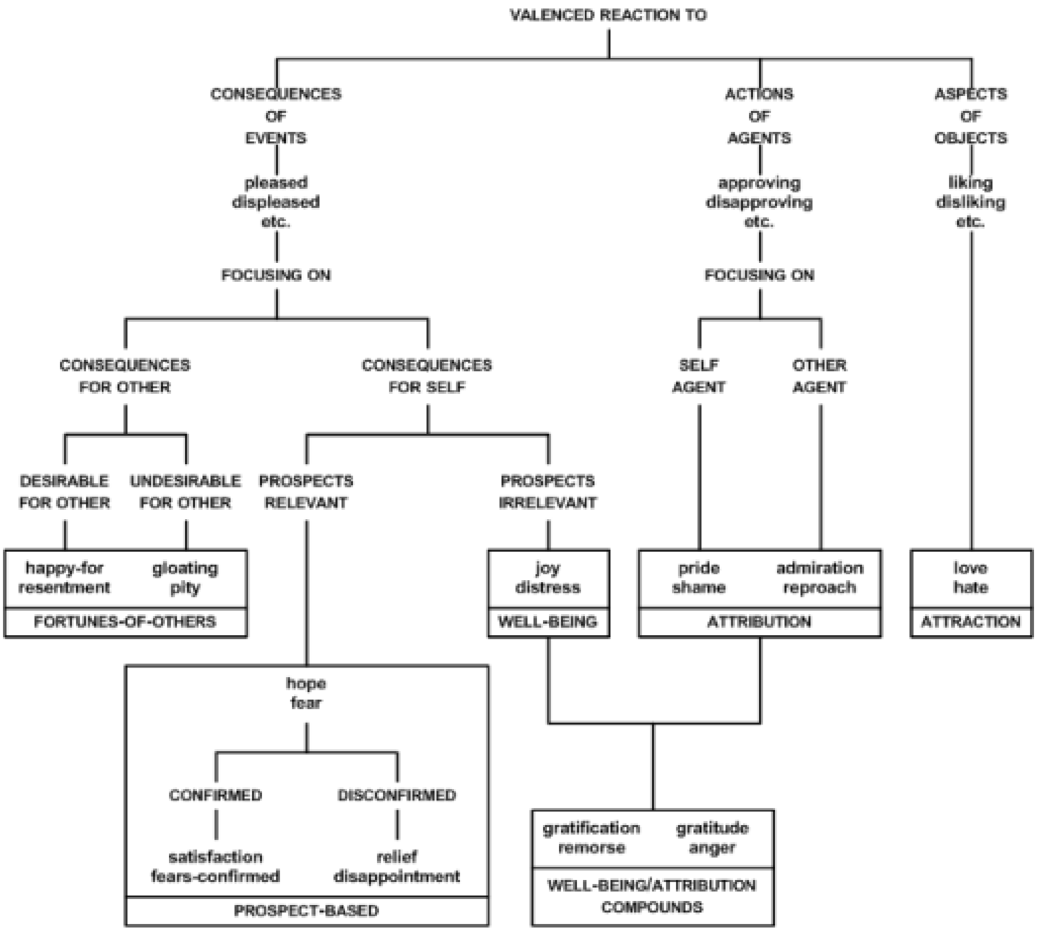
Both emotions and moods help people to process information and influence how they deal with situations presented to them [8]. However, there are facts that differentiate them. One difference between mood and emotion remains in the time domain. Emotion is related to punctuated events, so there is no connection between the moments in time in order to understand the sequence of emotions. This fact allows us to characterize any moment by a single emotion like a snapshot [9]. For example, an emotion of anger might last for a few seconds, but an annoyed or irritable mood may persist for several hours or for some days. Another difference is their focuses. On one hand, mood researchers have the attention mainly and almost exclusively on subjective and phenomenological experience. On the other hand, emotions have been viewed as multimodal psychophysiological systems as shown above on the perspective of Emotions [10].

2.1.2. How to represent emotions

Emotion is a difficult concept to universally agree on. Therefore, in order to develop methods to determine what is the emotion of a given person, researchers created models, some of those are presented on the next sub-sections.

2.1.2.1. The Ortony, Clore and Collins (OCC) model

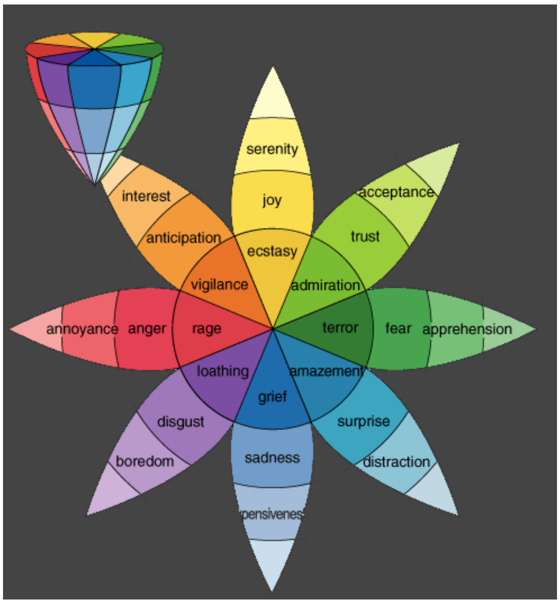
This model [11] was developed to be implemented on a computer and to be used in an Artificial Intelligence application, for the purpose of tracking emotions. This tracking system starts, not with emotions themselves, but how people



perceive the world. The supposition is that there are three major aspects or changes in the world, which are events, agents and objects. The base of their assumption is that emotions represent valence reactions of these perceptions of the world. This model hierarchically is described by 22 emotion type specifications. In this model there is a representation of emotions that can be induced by music such as soft, neutral and aggression and happy, neutral and sad [12]. They created a diagram of types of emotions which is represented by Figure 2-1.

2.1.2.2. Wheel of Emotions

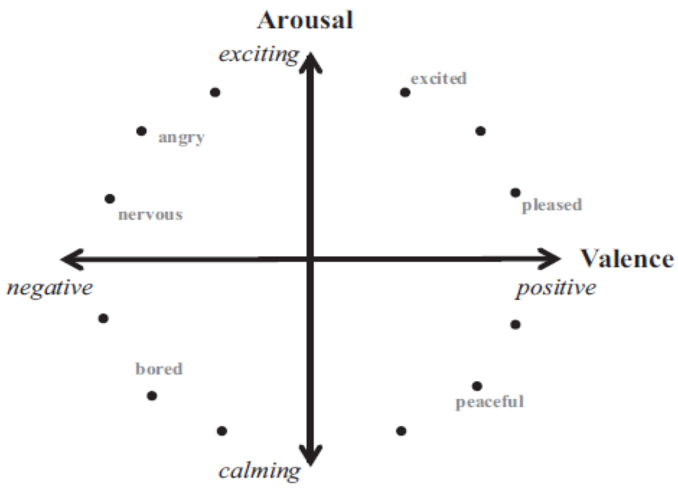
Another model of theory of emotions is the wheel of emotion from Plutchik. It is a three-dimensional circumplex model that describes relations between emotions. Eight primary emotions can mix with each other and form another emotion. The intensity of each emotion increases as it moves towards the wheel's centre. This wheel allows similar emotions to be grouped together and opposites one to be 180º apart.



This theory is interesting and it can be used in this thesis since we can identify one emotion by sensing two basic emotions or deny an emotion because it was the opposite of the emotion that was expected. This model is represented on Figure 2-2.

2.1.2.3. Arousal-valence Space

Two-dimensional arousal-valence emotional is widely used in music emotion detection or recognition and it is represented on Figure 2-3 [12]. Valence describes how positive or negative an emotion is classified and ranges from unpleasant to pleasant feelings. Arousal refers to how excited or how apathetic an emotion is classified and ranges from sleepiness or boredom to excitement [13]. Dimensional emotion theory believes that emotion should be analysed in a psychological dimensional space, as it helps to represent a wide range of emotions not necessarily depicted by a particular emotion descriptor [12].



2.1.3. Understanding the Emotional Information

To determine what the emotion of one person is, it is necessary to know what, when and how to measure.

What to measure - It is necessary to define how complex the emotions will be defined. Increasing the number of emotions will result on more complex and difficult to differentiate each emotion. The emotion theories or models can have:

- One layer – Basic emotions: It only has basic emotions that can be easily distinguished. Pekrun examined the academic emotions and defined them into one layer. This emotions are divided into four positive: joy, hope, pride and relief and five negative: boredom, anger, anxiety, shame and hopelessness;
- Two layers – Basic/Primary and Secondary emotions: It is possible to distinguish between primary emotions, such as anger, fear, happiness and sadness and secondary emotions, like hope and shame. The OCC model and the Pluchik model are examples from that, where the first model has 5 basic emotions and 14 secondary emotions and the second model has 8 basic emotions and 8 "advanced" emotions.

- Three layers – They have basic, secondary and tertiary emotions. Parrot model is one type of model which uses three layers of different emotion's complexity. On his model he has defined a primary layer with the emotions: love, joy, surprise, anger, sadness and fear, a secondary or feeling layer with affection, pride, irritation, etc., and a third layer with desire, relief, depression, shock, ect..
- Four and more layers: Kort and Reily [14] have attributed a 6x6 possible emotion axes (anxiety-confidence, ennui-fascination, frustration-euphoria, dispirited-enthusiasm, terror-excitement, humiliated-proud) that may fluctuate from the range of negative (-1) to positive (1) valence [5].

Instead of layers to define the complexity of emotional states, it can be used gradual emotion dimension. Hascher [15] has classified the following dimensions:

- Arousal (deactivating/activating);
- Valence (pleasant = positive, unpleasant = negative and ambivalent);
- Intensity (low-intense);
- Duration (short-long);
- Frequency of its occurrence (seldom-frequent);
- Time (retrospective like relief, actual like enjoyment, prospective like hope);
- Point of reference (self-related like pride, orientated towards other people like sympathy or referring to an activity like boredom);
- Context of an emotion (during learning, in achievement situations, during instruction, etc.).

When to Measure: -To know what the affective state of one person is, it can be known before, during or after performing one task. They can be measured:

- Before a task: Emotions, mood and feelings are used in order to predict a future emotion. For example, positive mood embrace holistic and creative ways of thinking, but negative mood leads to a pessimistic perceptual attitude diverting a person to aspects irrelevant to the performing of one task;

- During a task: The emotion is identified while a person is performing a task and can be done with psychological tools through self-reporting, physiological sensors, through signalling and motor-behaviour through observation;
- After a task: After the accomplishment of the task, it is perform an evaluation of the user's affective state by the identification of the respondent's emotional state in past sessions.

How to measure: -Researches indicate that emotion detection must be objective, unobtrusive, non-invasive, in real time with the task, inexpensive, no need of special expertise and language and culture-free.

There are three areas of emotion measurement:

- **Psychological:** The only way to measure user's subjective feelings, although it cannot be precise. Due to this fact it is avoid by researchers because the subjects are often reluctant to show their inner feelings to avoid constraint. They are unobtrusive and non-invasive and employ verbal and non-verbal descriptions of emotions. It also has the problem to not be used in parallel with the task [5].
- **Behavioural:** This strategies include evoking expressive gestures consistent with the emotion of the situation to cause the appropriate detection of it [16]. The studies of this affective state recognition focuses on the audio-visual features like facial expressions and speech.
- **Physiological:** Since there are physiological changes on emotional states, emotions can be recorded using sensors to detect emotions [17]. Since the physiological data are the dominant data of this thesis and bio signals tend to provide more detailed and complex information as an indicator for estimating the emotional state [18], it will be described on the next chapter.

2.1.4. Self-report measurements to know the user's emotional state – Psychological tools

At the beginning of one system, it is important to know the emotion the user is feeling, in order to associate it to the physiological signals. With that information it is possible to know what physiological changes can identify the user's emotion. In general, there are three main approaches to auto-evaluate the current emotion: self-assessment Manikin, categorical and dimensional. The self-assessment Manikin method is a non-verbal pictorial technique that directly measures the valence, arousal and dominance associated with a person's affective state through a group of numerated pictures [19]. Categorical approach treats emotion as distinct class from each other using terms to describe emotions, for instance, sad, dreamy, happy, exciting and vigorous. There is no standard taxonomy system for this method. Dimensional approach uses positions on abstract dimensions to identify emotions, for example, in a valence and arousal dimension [20].

2.1.5. Summary - Emotional deduction

It is arguably not possible to measure the emotional state of one person, because it cannot be measured. There is, however, the possibility to deduct the emotional state based on physiological measures. However, some inaccuracies can happen as it is a very hard task to uniquely map physiological patterns (e.g. time, context, space, culture) onto specific emotional states. Thus such physiological patterns correspond uniquely to one individual and to a single situation. Then to record physiological measurements the user needs biosensors and sensing using surface electrodes which are attached to the body. Finally, the use of various biosensors at the same time, with specific characteristics becomes a complex multivariable task and requires knowledge of biological processes related to neuropsychological functions, which makes hard to identify emotions based only on collected signals.

Nevertheless, the usage of biosensors provides some advantages as it is possible to continuously gather information about user's affective states. Since automatic nervous system (ANS) actions are mostly involuntary, generally they cannot be triggered intentionally, ANS physiological sensors can claim the user is telling the truth or not. For instance, it is unusual that a person smiles and have a negative emotion [21].

2.2. Physiological sensors

Sensors are used to provide a system with useful information concerning features of interest on the system's environment. A sensor is defined as a device that converts a physical stimulus into a readable output, and usually they are used to know the occurrence of an event or when to end an action. There are some types of sensors, and they can be:

- Mechanic: they detect movements, positions and presence, using mechanic resources. This type of sensors are very used in the industry to know if a structure reaches the end of his route (through one end limit switch);
- Magnetic: they detect the position of one piece or one part of a mechanism by putting one magnet to them. In the industry, where it is necessary to have quick responses, magnets are used because they have quick responses;
- Photoelectric: they use light and have very fast responses. In addition, they also don't have moving pieces that breaks or suffer detrition;
- Encoders: they are used to measure the position of a swivel axis and its velocity;
- Image: they are made from a big amount of photoelectric sensors that captures the shape, colour and other characteristics of one object. They are used, for instance, to detect defective objects on an assembly line;
- Measuring Optical: they are used to detect optical characteristics, such as luminance, contrast and colour.
- Thermal: they measure changes of temperature;
- Presence: they detect persons by their body's temperature or forest fires through their heat;
- Ultra-sonic: they are used for detecting objects in long distances when the objects have the capability of reflecting this type of radiation [22].

In this sub-section it is briefly introduced some physiological sensors that are used on emotional deduction by other researchers and which encloses various characteristics presented above. Based on previous literature, it was chosen the following physiological measurements: Facial electromyogram (EMG), Galvanic Skin Response (GSR), Skin Temperature, Oxygen Saturation, Electrocardiogram (ECG), Electroencephalogram (EEG), Respiration and Blood Volume Pulse (BVP). These sensors will be analysed in order to determine the most appropriate sensors in order to use in this dissertation.

2.2.1. Facial EMG

It is a type of electromyography which is related to muscle activity or frequency of muscular tension of one muscle, and it is measured with sensors [23]. Since EMG records muscle contraction, the higher the muscle strength due to emotion is, the higher is the amplitude recorded by EMG [24]. Facial EMG is focused on muscles of face. It is commonly measured from a number of target sites, which can be the masseter (the muscle above the jaw), the corrugator (the muscle above the eye brow) and the zygomatic major (cheek). The masseter is associated with arousal and valence. The corrugator is associated with emotions with significant arousal such as anger or surprise. But Facial EMG cannot be precise because one muscle movement is not for a specific affective state. For instance, there is higher activation of the masseter EMG when an individual is smiling and frowning and this can point to joy and grief [17].

2.2.2. GSR

It is easily measured with variation of resistance or conductivity of skin. GSR is measured through sweat glands - eccrine glands. Usually, it is measured where there are many sweat glands which can be found on palms and soles. GSR values reacts to body temperature changes and physiological changes. The eccrine glands have a similar function of a variable resistor, has their value decreases with the increase of sweat, even if the sweat isn't visible [23]. GSR sensor is considered to be sensitive to changes in arousal, as the measure tends to increase with arousing emotions and decrease for deactivating ones. According to Alzoubi et al. [17], there are changes in GSR with emotion stimuli such as music, violence and erotica that can be useful for this thesis. GSR can also differentiate some emotions such as fear and anger, fear and sadness, and happiness and sadness. It can also be used to detect both valence and arousal.

2.2.3. Skin temperature

Skin temperature measures the temperature at skin surface. Changes in skin temperature can be caused by vascular resistance or arterial blood pressure. Vascular resistance is inflected by smooth muscle tone that is mediated by sympathetic nervous system. Arterial blood pressure variation is resulting of cardiovascular regulation by automatic nervous system. Since skin temperature variation reflects activity from ANS, it is also an indicator of emotional stimuli [25].

2.2.4. Oxygen saturation

Oxygen saturation is defined as the amount of oxygen dissolved in blood, based on detection of Hemoglobin and Deoxyhemoglobin. To detect this, the sensor emits two different light wavelengths to measure the difference on the absorption coefficients, because deoxygenated (deoxy-Hb) and oxygenated hemoglobin (oxy-Hb) absorb different wavelengths.

Normal ranges of oxygen saturation are from 95 to 99 %, those with a hypoxic drive problem would expect values between 88 to 94 percent and values of 100 percent can indicate carbon monoxide poisoning [26].

Oxygen saturation is one parameter of pulmonary and cardiovascular function, but some researchers couldn’t get patterns to identify emotions with this sensor [27][28]. However, this sensor is described to register changes on their readings with musical influence, with changes in oxygen-saturation levels when one person is subjected to musical stimulus [29].

2.2.5. ECG

ECG is a record of the electrical activity of the heart that generally follows a rhythm pattern. It consists in the nervous innervation of the heart muscle that makes one left pump to receive venous blood from vena cava and then one right pump to deliver oxygenated blood through circulatory system. The ECG revels several characteristic inflection points that are used for clinical utility. Typically, it is used 12-lead to monitor an ECG. However the ECG can also be used as a biometric tool. Forsen [30] applied a less-invasive technique with only two electrodes that were attached to the index fingers without other lead. According to Silva and colleagues, using 12 –lead ECG and 63 seconds of recording, this method has an accuracy of 100% from a collection of 26 subjects. With the same recording, it was only analysed a single heart beat and it had an accuracy of 92%. The most useful features that can extract from an ECG to identify emotions are:

- HR: reflects emotional activity. It has been used to differentiate between positive and negative emotions, with the help of finger temperature;
- Cardiac interbeat interval (IBI): Time between successive peaks of the R-wave of an ECG;
- Heart Rate variability (HRV): oscillation of the interval between consecutive heartbeats. It can show the mental effort and stress in adults. It can be a useful measure in high-stress environments [24].

2.2.6. EEG

EEG is a record of electrical activity of the brain that is recorded on the scalp. It is applied sensitive electrodes on the scalp in order to record the electrical activity of all organisms with central nervous system. The current generated by nervous tissue activity is very small, around 10-50 μV. The brain can be divided by modules, which are responsible for physiological functions such as emotion, memory, vision, and related sensory, motor and so on. Since this is very complex area, to do a recording using EEG, it can be used 18-256 electrodes that are positioned on the scalp [30]. To examine the relationship with emotional states, the power spectra of the EEG is often assessed in distinct frequency bands, such as delta (δ: 1-3 Hz), theta (θ: 4-7 Hz), alpha (α: 8-13 Hz), beta (β: 14-30 Hz) and gamma (γ: 31-50 Hz) [18], but most researchers focus on alpha power, which is thought to be inversely related to regional cortical activation. There is also greater relative left frontal activity associated with positive emotions, while greater right frontal activity associated with negative emotions that are termed as "frontal asymmetry". It can also establish differential roles of left and right prefrontal cortex regarding pleasant and unpleasant emotional information, respectively [19].

2.2.7. Respiration

Breathing activity can be monitor through one latex rubber band. It can be worn either thoracically or abdominally. The most common measure is respirations rate and depth of breath. In the case of respiration's slow rate, it can mean not only a relax situation, but also startling events and tense situations. But if occurs an irregularity in the measurement of respiration, if generally indicates a negative emotion. Because respiration system is linked to cardiac function, it can affect other measurements, like EMG and GSR measurements, and this influence must be take into account [24].

2.2.8. BVP

It measures the amount of blood that flows through human body with a photoplethysmograph. When heart beats, it causes a volume of blood to travel from the heart to the peripheral regions of human body. After a period of time, that blood volume will eventually return to the heart. Due to the relation between volume of blood and heart functionality, it is possible to determinate HRV, HR and cardiac IBI [31]. This physiological sensor as the inconvenient of change with room temperature where the person is and is very sensible with its installation and with movement [23].

2.2.9. Information of sensorial analysis

Table 2-1 is summarized the relative aspects of how each sensor is used to acquire information, their placement in human body and emotional features. Table 2-2 compares positive vs. negative aspects from each sensor, pointed by other researchers on the emotional field. Both these tables will be used to define what are the best sensors to use in this work.

Table 2-1: Overview of some physiological sensors and what features can be extracted from them

Physiologic method to detect an emotion	How to measure	Placement of the sensors	Features
Facial EMG	Small sensors are placed over a specific facial muscles and its electrical activity reflects changes in muscle tension that results in facial expressions [32]	Facial EMG at the *corrugator supercilii* and at the *zygomaticus* [21]	Extract emotional valence [32]; Mean, SD corrugator supercilii (frowning); SD zygomaticus major (smiling) [33]
GSR	Measured through the sweat glands - eccrine glands, usually on palms and soles with surface electrodes sewn in Velcro straps [23], [34]	Electrodes placed around two fingers on the same hand [34]	Good response with emotional stimuli such as music; it is linearly correlated with arousal changes in emotional ANS activities while listening to music; can differentiate fear and anger, fear and sadness, and happiness and sadness [17]
Skin Temperature	It measures the skin temperature [35]	Peripheral temperature at 3rd finger of non-dominant hand [21]	Mean, SD Temperature [33]
Oxygen saturation	It has two different light wavelengths to measure the absorption spectra of Hemoglobin and Deoxyhemoglobin [26]	A pulse oximeter sensor is placed on one finger	Oxygen dissolved in blood [26]
ECG	It records the electrical activity of the heart [30]	It is placed three pregelled surface electrodes, two on the chest and one electrode on the abdomen [34]	HR; SD IBIs; RMSSD IBIs; LF power; HF power; VLF power; Pulse transit time.[33]
EEG	It is used a cap with 18-256 scalp electrodes [30] to capture the nervous system responses	Sensors over the scalp [30]	It was find correlations between human emotions and significant EEG features extracted from raw data [36]
Respiration	Sensors measures how deep and fast a person is breathing [35]	It is applied a rubber band around the chest [35]	Respiration Rate; amplitude respirations; respiratory sinus Arrhythmia [33]
BVP	It measures the amount of blood that is running through vessels, e.g., in a finger of one person [35]	It is applied a photoplethysmograph – light source and photo sensor – attached to skin. The amount of reflected light depends on the amount of blood passing through it [35]	HR; SD IBIs; RMSSD IBIs; LF power; HF power; VLF power; Pulse transit time [33]

Table 2-2: Positive and Negative aspects regarding the use of each physiological measurement

Physiological methods to detect emotions	Positive aspects	Negative aspects
Facial EMG	It is able to measure changes in emotional valence [32]; Good results with other monitoring systems	Limited information that can only inform how positive or negative an emotional state is [32]; need other monitoring system [17]; invasive; obtrusive
GSR	Good with music stimuli; sensible to changes in arousal; it is correlated with arousal changes in emotional ANS activities while listening to music [17]	Influenced by external factors
Skin Temperature	Emotions change skin temperature	Slow indicator of changes in emotional state [35]; influenced by external factors
Oxygen Saturation	It is a non-invasive method and easy to read	There are studies that don't get any change with oxygen saturation [27]
ECG	Can get 100% accuracy [30]	Invasive when using all day
EEG	Since it's measures are derived from central nervous system, it is recognized as a superior metric when compared to the other physiological sensors in the emotional evaluation [36]	Only a small set of labeled samples is available to use; noisy channels [37]; invasive; obtrusive
Respiration	Negative emotions usually cause irregularity [24]	It can be inconclusive [24]; invasive when using all the day
BVP	It can be used to measure vasoconstriction and HR [35]	Obtrusive

2.2.10. Summary of the most proper physiological sensors to use in this dissertation

Regarding the sensors described earlier and tables above, the most interesting to use is GSR and BVP. GSR was referred to be linearly correlated with arousal changes in emotional activities, while a person was listening to music [17]. BVP can get a lot of information useful to identity the present emotion, since it can afford some characteristics of an ECG and it does not cause the same discomfort as the ECG. In research it was mentioned that HR is not good to identify one emotion, and instead of it can be use HRV, because it provides better emotion information and is more constant in situations where someone is happy and relaxed, whereas it shows high changes in more stressful situations [33]. To get better results, it can be necessary to combine more than one sensor to get other features, for instance, HR, HRV coupled with Respiration features could distinguish between four basic emotions: anger, fear, happiness and sadness [17].

2.3. Music use and its influence in emotional states

The use of physiological measurements is increasing. They can be presented in several devices and their connection with Internet is becoming more evident, which was already shown in section 1. This technology can be used to infer about user's emotional state through the identification of changes in physiological signals. This changes could be important to discover emotional stimulus that could be used for the user, to make him feel better. One example of an external element that could change a person's emotional state is music. This sub-section has the objective to demonstrate the importance that music has in our technological society and different situations that music could be applied in order to make musical stimulus over each person. This sub-section gives a brief analysis of investments, made by European Union and United States, over projects related to music and its effects in our society. In this section it is also described several applications with the same purpose of the developed system of this dissertation.

2.3.1. R&D in Technology – The use of Music for our Well-being

Under FP7 (7th Framework programme), there were many projects related to music and using it for human wellbeing. The "Beat-Health" project (project number 610633 funded under FP7-ICT), was one example from that. This project intended to study the relation between music and movement for boosting individual performance and enhancing health and wellness. This fact can be seen in gyms, when the rhythm of music changes according to the objective of one class. A spinning class, for instance, usually has a variety of rhythms to make users feel like they are into a sprint, with a fast beat, or make people feel they are climbing a hill, with a slower beat. In this program it was developed an intelligent technological architecture to enhancing and recovering features of movement performance. Another project related to the developed system was the "Prometheus" project (project number 214901, funded under FP7-ICT). In this project, researchers developed one framework to link fundamental sensing tasks to automated cognition processes. This goal was achieved using a network of heterogeneous sensors that monitor one environment or group of people, in order to understand human behaviour and different patterns. One example of that applicability is in the security, to detect abnormal behaviour in real time, for instance, when a person is caring a luggage and drops it.

For the next year, regarding the activities of 2016-2017, the European Commission, for the ICT in Horizon 2020, will give the following budgets:

- SC1 – Health, demographic change and wellbeing: 124.2 M€. This sector is related to personalised medicine and the projects are related to active ageing and self-management of health, protection and health's methods of data and coordination activities related to health and wellbeing;
- SC6 – Europe in a changing world – Innovative, inclusive and reflective societies: 70 M€. This social challenge include activities related to public sector modernization.

For the next year, the two of the three focus of the areas of the ICT working program will be:

- IoT;
- Smart and sustainable cities [38].

2.3.2. Current applications

Music plays an important role in our everyday lives, even more in the digital age. As Figure 2-4 shows, there is an increase for the downloading revenue for digital music of 3.3 percent annually from 2013 into 2018 [39]. It is possible to conclude that more people are listening to music and even more are preferring using digital music which is relevant for the use of the developed system.

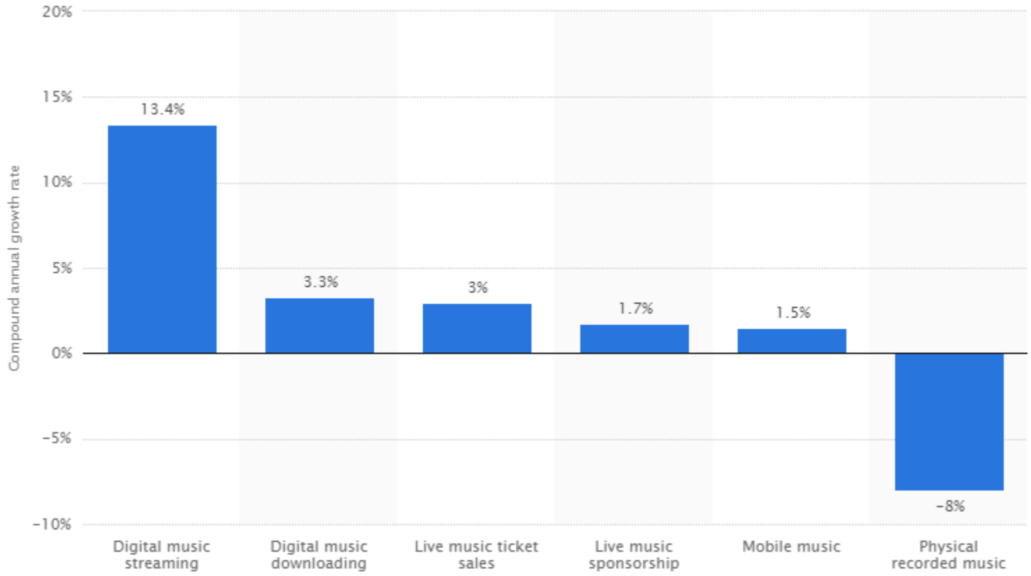
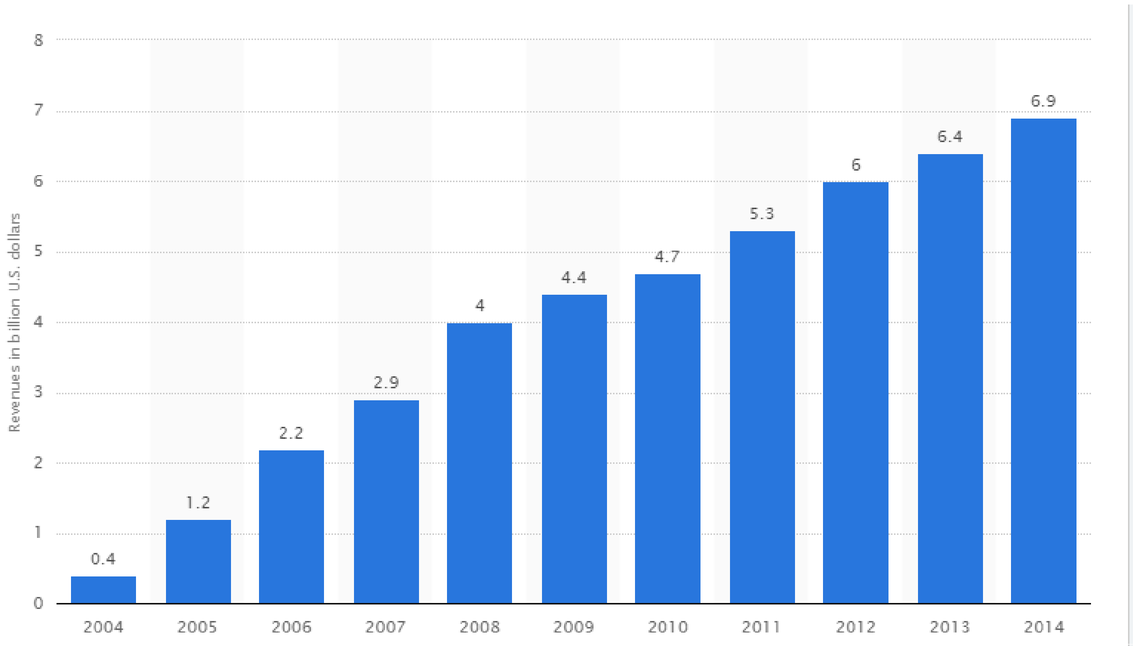


Figure 2-4: Growth of the global music revenue between 2013 and 2018, by category [39]

Since the behaviours of the citizens are changing, there are an increase of online music platforms such as iTunes, streaming services such as Spotify, web-sites and TV shows such as VH1 or YouTube or the increasing of radio stations across the broadband, there are a music digital revenue from 2004 to 2014 of 6.5 billions of dollars, as can be seen on Figure 2-5, making this subject an economical interest for developing new attractions for the users.



As the population's needs are listening more music and using more the digital music, this system was developed taking into account two different cases: having the possibility to control the most appropriate music for an individual (or group of persons) or for investigation purpose.

2.3.2.1. Controlling background music for a group use

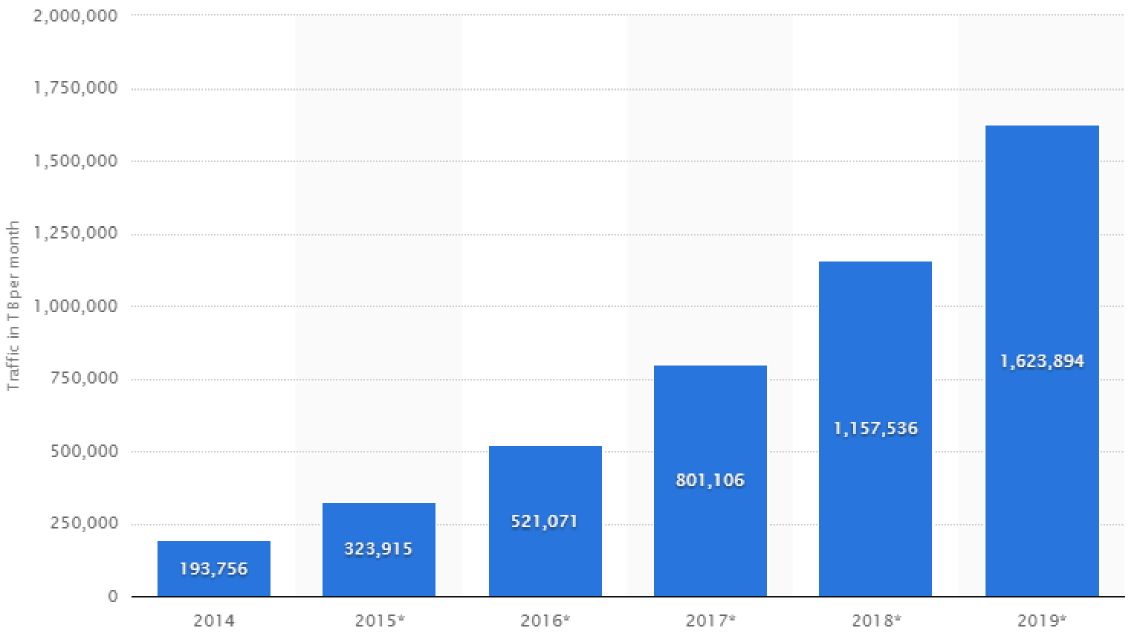
Music is present is many public places we go. Trains, buses, elevators, restaurants or hospitals are some public areas that uses music as background music. And if it was possible to define that music according to the majority of the emotional state of the users of these spaces? Could this simple change make the citizens happier? On [1] it was concluded that using music in a Smart Space had influence on reducing blood pressure, increased respiration (suggesting physiological responses to perception and enjoyment of music) and lowest mean of EEG (suggesting the physiologically important aspects of appealing music therapy during relaxation). Also experimental studies [2] showed that listening to positive music (the music had to be positively valenced), when they try to improve their mood, was an effective way of improving happiness, experiencing greater gains in well-being, as measured by positive affect, subjective happiness and life satisfaction. The participants reported higher levels of happiness when listening to positive music while trying to feel happier, in a two weeks period. Imagining a public space where students or employees go for a coffee break. If it was possible to know the generic emotional state of the group of people, it was possible to play one music that could improve their feeling state and improve the citizens' quality of life.

With these studies, of the importance of music in our well-being, it is possible to confirm the utility for the public service of this types of systems. But, it is possible to know the feeling states of the citizens without physiological measurements like sensors? The answer to that question is yes! The feeling state of one person cannot be only inferred by physiological measurements. There are used several modalities to interpret emotional states, because emotions affects almost all modes: audiovisual (facial expression, voice, gesture, postures, etc.), physiological (physiological measurements) and contextual (goal, preference, environment, social situation, etc.) states in human communication [24].

2.3.2.2. Controlling background music for Individual use

Instead of viewing the applicability of this dissertation for a group of persons, it can be used for an individual use. Many people individually listens to music while traveling, waiting or studying. It could be useful to choose the music according to the current feeling state of the user, instead of a random selection.

With the advance of technology and network communications, the use of mobile phones for listening music is increasing every day. Analysing Figure 2-6, which represents the use of internet for listening music, there are a huge increase of musical data acquired from the network, with global mobile audio streaming traffic from 2014 to 2019 having an increase of approximately 193 756 TB to 1 623 894 TB per month.



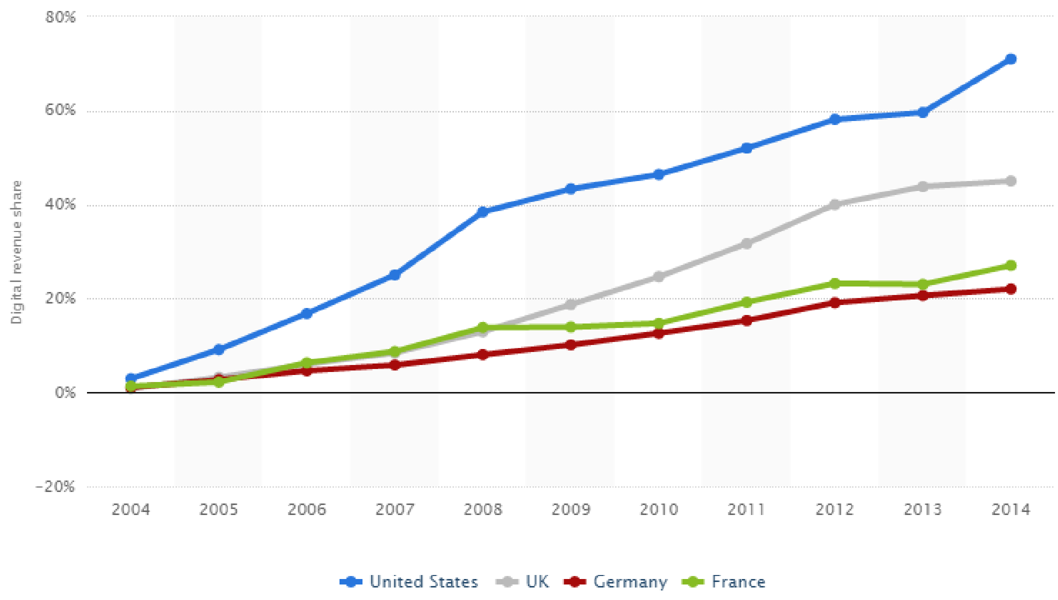
There are mobile phones that can extract health features and useful information through their sensors. With stride length and gait cycle time, acquired from a tri-axial gyroscope from a mobile phone, it is possible to use them as biometric identifier for the user. There are already mobile phones that are capable of getting a readable ECG of their user. This information allows to estimate the HR, HRV and cardiac IBI – with this information it is possible to infer about the users' feeling state. Using their accelerometer, they are also capable of monitor the movement during the sleep, to determine which sleep phase the user is in, and according to that information, the cell phone will turn on the alarm on the lightest sleep phase, to help the user feel rested and relaxed. Related to sleep quality sensing, other programs use the microphone of the smartphone to detect events that are related to sleep quality, including body movements, couch and snore [40]. Other study [41] analysed the influence of mobile phones while the users were using them to communicate with others. They use the information of the time of the mobile phone usage, phone and location data to give information of sociability and timing of calls, SMSs, emails, "screen on" to provide information of how often the users interact with phone during the day and the night. With all these sensors that most people already have with them every day, it is possible to use them, to deduct their emotional state and automatically propose the most appropriate music to make the user feel better while listen to that music.

2.3.2.3. Investigation Use

To understand the effects of music on our body and mind, it is necessary to measure it, through physiological sensors and see its information. This is precisely what the system is capable of. One future work to be done with this system is the observation of physiological measurements of playing the same music but in different circumstances, for example, first is play only the music, then the music is played but with its videoclip, and finally the music is played with a totally different video.

The investigation of the music area is a situation that is increasing with the technological evolution. This big global investment can be seen by Figure 2-7. Between 2004 and 2014 the digital share of music revenues grew for the analysed countries.

This dissertation uses music to make the user feel better. But in order to that, it is necessary to acquire information from different physiological sensors and analyse that information in order to know what is the emotional state of the user. This interpretation by different components will be analysed on the next sub-chapter.



2.4. Some Interoperability issues and resolution approaches

To be possible to infer about user emotional state, it is necessary to understand and use the information acquired by each sensor. The interpretation between this two different systems requires the so-called interoperability. Interoperability is the ability of two or more systems or components to exchange information and use the information that has been exchanged. A practical example addressing this issue can be presented through a scenario, which one of its systems (system 1) wants to communicate with another one (system 2). If system 1 uses data format A and system 2 uses data format B, they cannot understand each other. It is necessary, for example, to create a function or even another system to convert the data format A to B and B to A, or introduce a standard format in the middle for both systems use it [42].

There are typically three main levels where interoperability can occur. These levels are: organizational level, technical level and semantic level.

At an organisational level, interoperability can be achieved when organizations collaborate with each other in order to meet their business objectives, creating new bonds within an enterprise and across the organizational borders that need to interoperate [43].

Another level that interoperability can be noticed is at a technical level, which takes place on the hardware and software. An interoperable software and hardware is created due to the existence of many systems (devices, sensors, etc.) that need to communicate and use each other data formats, as well as new systems entering on the same environment which possesses new formats and standards not foreseen in the environment. This connection between the systems enables the exchange of data without the need of being remanufactured because the manufacturers only need to provide interoperability information of their own hardware allowing them to connect with other devices [42].

At a semantic level, interoperability ensures the exchange of information between two or more systems and having the meaning of sent information automatically and correctly interpreted by the receiving system. To have semantic interoperability, the semantic of the original message must be preserved. As a consequence, it is necessary to transfer a message that includes all the information required by the receiving system to interpret its meaning correctly whatever the algorithms used by the receiving systems (which may be unknown to the sending system) [44] To have a semantic system, the system must have the capability to adapt the existent semantics to new acquired knowledge [45].

2.4.1. Interoperability on Electronic Health Records (EHRs)

This sub-chapter presents an example of interoperability resolution in the health domain. The variety of EHR makes interoperability an important trend in healthcare. In particular, semantic interoperability as a special attention since it ensures that different health information systems make the same interpretation of the exchanged information.

There are already different health standards, such as Health Level Seven (HL7) that enables health information systems to integrate by communicating standard information. Another one is Integrating the Healthcare Enterprise (IHE) that defines integration guidelines based on established data standards (e.g., HL7).

But there are some problems with the existing standards to achieve semantic interoperability. Firstly, interoperability standards provide limited mechanisms to validate the information to be exchanged between the different systems. Secondly, they do not ensure the same interpretation of the exchanged information from one health information system to another. Thirdly, the health interoperability standards require high effort, technical expertise as well as clinical domain knowledge. Finally, it is not possible to use all the standards together to achieve semantic interoperability.

2.4.2. Health Informatics Standards

System's communications are usually adapted for exchanging data through one type of protocol. This fact represents one handicap, because it cannot be interoperable with other systems. To reduce this problem, communication protocols should be the same for all equipment, in order to one system understand information from any different system that connects with it. To show that importance, there will be exposed 3 different protocols to support clinical information.

2.4.2.1. OpenEHR

Consists on a generic information model, application-specific archetypes and context-specific templates. It has generic data structures for the health care domain (observation, evaluation and history). This archetypes allows the definition of clinical concepts (e.g. HR), which are expressed on a generic reference model, define semantic rules that guarantee the correct and full interpretation of the clinical concept (e.g. HR constraints). It also templates package the archetypes in terms of forms that are useful to a particular clinical situation.

2.4.2.2. HL7 - HL7 Messages

This health informatics standard was developed by a not-for-profit organization, focused on interoperability standard in the health care domain. They focused on supporting the exchange, integration, sharing and recovery of electronic health information. These messages define the language and data structure required for seamless information integration among health information systems. Each segment contains one specific category of information that use ASCII (American Standard Code for Information Interchange) on segments and one-character delimiters (e.g., |, ~). In every message the first segment of information defines the message type.

2.4.2.3. IHE

It is an initiative by healthcare professionals and industry to improve how the health system shares the clinical information. It promotes the coordinated use of established standards such as HL7 to address specific clinical need in support of optimal patient care. IHE proposes Integration Profiles to provide precise definitions about the implementation of health standards to meet specific clinical needs with a common Framework. Research tells the systems develop according to IHE communicate with one another better, are easier to implement and enable care providers to use information more effectively [46].

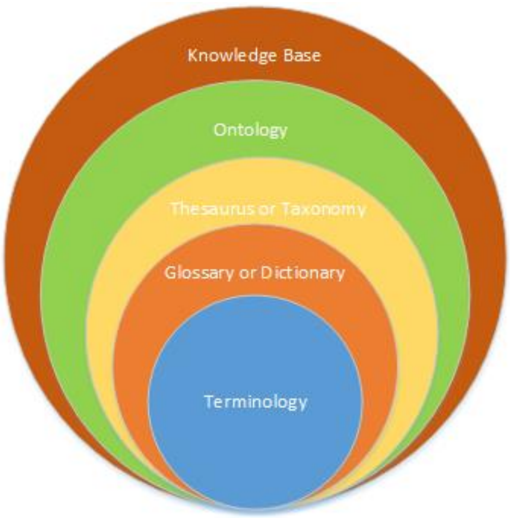
2.4.3. Syntax and Semantics

The exchange of information can only be possible with semantic interoperability. Semantic is a verbal concept that allows differentiation from other concepts within a system of concepts. Semantic is informal when it creates meanings that people can understand or is formal when it creates meanings that machines can process [45].

To represent correctly one semantic system, it is necessary to define certain terms. *Data* can be defined as symbols and alone it doesn't have significance beyond its existence. Data doesn't have meaning of itself. An example of data is the output from a sensor, which can give a number, accordingly to the sensor or the situation, for example 19. This number alone does not have any meaning. *Information* is data that are processed to be useful. Information has meaning by the way of a relational connection. In the sensor parlance, information can be, for example, 19º C. *Knowledge* is the appropriate application of data and information in order to be useful. When a person "memorizes" information, that person collects knowledge. *Understandability* is an interpolative and probabilistic process. It is the process in which someone can take knowledge and synthesize new knowledge from the previously held knowledge. Understanding can bring the capability to build upon currently held information, knowledge and understanding. In computer parlance, an AIS (Artificial Intelligence System) possesses understanding in the sense that they are able to create new information and knowledge from the previously stored information and knowledge. *Wisdom* is an extrapolative and non-deterministic, non-probabilistic process. Not only uses the previous levels of consciousness but also uses special types of human programming, e.g., moral and ethical codes. With these features, it asks questions, to which there are no answers, reason or judgement between right or wrong, good or bad. This characteristic isn't present on computers [47].

2.4.3.1. How to formalize knowledge

In order to gather all the information about the health sensors, it is necessary to create one knowledge base, in order to gather all the knowledge of the system. This knowledge base can be represented based on Figure 2-8.



At the lower level, there must exist a *Terminology*. It is the set of designations used in the special language of a subject field. They are used upon the process of fixing/stabilizing the language within a domain and a linguistic community as well as the facilitation of unambiguous communication [48]. At the next level there is a ***Glossary***. The glossary is all the terminology and the corresponding description, mostly unique to a specific subject. It can include descriptive comments, definitions, synonyms and references. One use of glossary can be to unify knowledge sharing. These terms are directly connected to the source document.

Instead of a glossary, it can be made a *Dictionary*. On a **dictionary** are listed words in a specific language with definitions, etymologies, pronunciations and other information. This component can also have listed words in one language with their equivalents in another language (lexicon). This tool is useful because it reduces miscommunication and because users can search for new terms and abbreviations in one local and lessens the mistake by homonym words [45]. The higher level is the classification system called ***taxonomy***. It is the study of classification, including its basic principles, procedures and rules. It is grouped items scientifically according to the purpose and codifying them with numerical identification according to certain principles [48]. Another type of classification system is ***thesaurus*** where its organization is based on concepts. It is a structure that manages the complexities of terminology and provides conceptual relationships through an embedded classification/ontology [49]. The highest level is ontology. Ontology is a common, shared and formal description for important concepts in a specific domain. It has the possible inter-relationships between the constructs used in and it has consensual knowledge, where the knowledge is not from the point of view of one individual but a general view shared and accepted by a group. It is also a machine understandable giving the opportunity to be translated into some form of logic [45], [50]. The goal of ontology is to classify most complex and widespread knowledge system automatically. It was used to help with the representation, organization, acquisition, creation, usage and evolution of knowledge. With the Information Systems, ontology has been the most used in knowledge management [51].

2.4.4. Ontology and Semantic Web

Due to the amount of user-specific knowledge and data needed to define what makes one user to be in a determined emotional state, it is necessary to organize existing information and search for the best result for that problem. To do this, it is necessary to have one engine which is capable of reasoning about all stored information about each user. This can be done with one ontology. Ontology is very used for knowledge representation and it is a description about domain concepts and their relations. It can differentiate kinds of objects (concrete and abstract, existent and non-existent, independent and dependent) and their relations or dependency. It can also be used to organize information in order to support information acquisition [52].

Semantic web is an extension of the current Web, which gives an easy way to find, share, reuse and combine information. It allows people to store data, build vocabularies and write rules for handling data, everything on the web. It has the objective to provide a better platform for knowledge representation of linked data to allow machine processing. This can be achieved by adding logic, inference and rules systems to the web, allowing data to be shared across different applications and everywhere [53]. It can be used the following methodologies:

- **Resource Description Framework (RDF):** It is the World Wide Web Consortium (W3C) standard model to describe metadata and ontology. It is usually used for representing and exchanging statements about information resources on the Web [54]. RDF is a XML-based standard (Extensible Markup Language) for describing resources that exist on the Web, intranets and extranets. It builds on existing XML and URI (Uniform Resource Identifier) technologies. RDF statements are often referred as "triples" that are composed by three parts: resources - subject, property – predicate and property value – object. Each triple encodes the binary relation predicate between subject and object, represented as a single knowledge fact [53];
- **Resource Description Framework Schema (RDFS):** It is an extension of RDF and has the capability of having vocabularies, taxonomies and ontologies. It has the property of describing taxonomies of classes and properties as well as defining the domain and range of RDF classes and their properties;
- **Web Ontology Language (OWL**): It is an extension of RDF and RDFS and it can define ontologies that capture the semantic of domain knowledge. It can convert all the things in descriptive logic that RDF and RDFS cannot do it [55]. The OWL ontology can be interpreted into RDF triples and the formalization of SPARQL over RDF

works also on OWL [56]. OWL is used to formally represent and integrate activity-related information originated from different data sources [57].

2.4.4.1. Protégé

Protégé is a free, open-source ontology editor and knowledge-base framework. The concepts and theirs relations are described in an Ontology framework, which can be formalized by a program, for instance, Protégé. Ontologies can be exported into a variety of formats including RDF, RDFS and OWL [58].

To implement and validate an ontology it was used protégé and it was involved in the following steps: firstly it was defined classes, properties and their relations; secondly it was created instances for the built ontology in Protégé-OWL; thirdly querying the ontology instances with SPARQL; finally it was compared the queries results with the instances insert into the ontology and if the result were positive, then the ontology was validated.

2.4.4.1.1. A language to query results from an ontology

SPARQL is a query language to define data access protocol and a standard query language to use with RDS data. Since RDF databases are collections of triples (subject, predicate and object), SPARQL searches each triple and return the desirable one [53]. To execute SPARQL queries it can be use Jena framework with ARQ (query engine) or protégé, which allows getting data from RDFS and OWL.

2.5. Relation to IoT Paradigm

Recent ICT technologies offer the possibility of connecting several devices to the Internet. The IoT paradigm has been defined as one evolution of the Internet, which enables devices to interact with each other using interoperability [59]. Since there are many different types of sensors, it is normal for a controlled system to have more than one type of sensor to complement the others sensor's information. These sensors are geographically dispersed in the environment and interconnected through a communication network. Although it is important to have large number of sensors, because they can bring new information and have better control on the system to be analysed, having a large number of sensors can bring problems of not having a real-time or near-real-time decision making as well as the capability of analysing and storing that amount of new data. The systems to respond to this problem are starting to emerge with the focus of being more efficient on sensor-based applications or improve sensor-based data management, sensor network configuration and sensor communication protocols [60]. This can be solve, for instance, by the use of one ontology. In the next subsection there will be presented two cases which uses sensors in order to acquire information of the environment where they are placed. The first example is the placement of sensors on a public area, in order to have information about their citizens. The second example is the applicability of sensors on each individual, in order to use the technology around them for their advantage.

2.5.1. Existing solutions

2.5.1.1. Sensors in Smart Cities

With the development of new technological innovations, mainly ICTs, the concept of "Smart City" emerges as a means to achieve more efficient and sustainable cities. It is complicated to obtain a common definition of Smart City because cities are complex systems where massive number of interconnected citizens occurs and there are a big diversity of technological, social, economic and organisational problems. A common goal of a Smart City is, not only the use of ICTs to meet theirs objectives, but also to provide a new approach to urban management, in which all aspects of a city are treated with interconnection of all urban aspects, improving this way the quality of living of their habitants. For this reason the researches on [61] used the sensor Radio Frequency Identification (RFID) as one technique for identify the citizen's movements. With this kind of architecture, it is possible to make infrastructure planning, for example, in the transportation routes or the optimal positioning of the city's resources. The citizen's traceability was sent into one cloud service and then a centralized service provider would define the best service according to the data acquired from the cloud.

2.5.1.2. Wearable Devices

Wearables are miniature embedded computer systems used by people. They sense human biological data and can acquire motion data and then convert them into digital signals, while the user is performing other tasks, without the need of direct user intervention. These devices can be equipped by several sensors, such as accelerometers, gyroscopes, HR monitors and galvanometers. These devices can have single functions, such as fitness tracking, health monitoring and message display. Others have taken on the integration of multiple functions in the same device, for instance, smartwatches that combines time, fitness and health-monitoring in the same device or the example of head-up display (HUD) glasses that integrates glasses with augmented reality [62].

Most of the wearables are connected to the internet via smart-phones, which can be considered a subset of the IoT. One important application of the IoT is the increase use of this devices on medical applications through their connection with internet. One example is the connection, though Wi-Fi or Bluetooth, of hearing aids and monitoring systems to phones and other devices, for long-term tracking of chronic illness [63].

In this dissertation there will not be used wearables. This dissertation will focus on this IoT area, with the use of sensors to monitor the user. One application that could be developed, using the system developed on this dissertation, is using its results/applications to be applied on the construction of wearables.

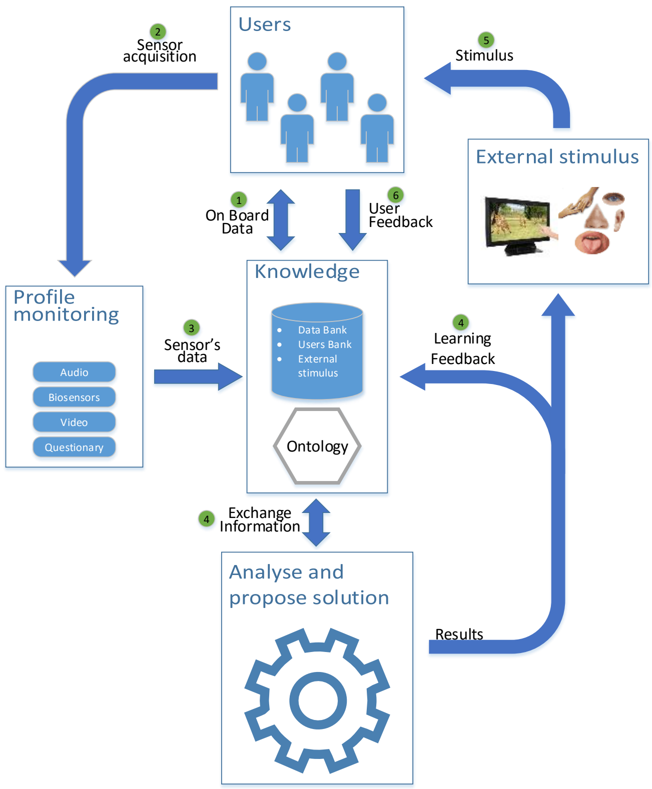
2.6. Summary

The usage of sensors with ontologies are increasing with development of technology. Information is becoming self-dependent with analysing and decision making which is aimed for improving life's quality of the citizens of our society. With the growing usage of sensors, in order to have more controllable and observable systems, there is an increase of flowing data that need to be read, analysed and saved, which can be done with ontologies. The research presented in this section shows that these two concepts are used in many different places and situations and the more they are used together, the more our society can benefit with them which complements the IoT paradigm.

3

3. Framework for User Profiling

In my research thesis, I aimed to create one system, interoperable with one module capable of acquiring data to deduct the emotional state of one subject and capable of describing and reasoning all information from each user and create new knowledge about it. To do this, it will be described on framework that can be used in applications that intend to analyse the user's profile and reacts to the deducted emotions processed by the framework.



The proposed framework is composed by five parts: users, profile monitoring, knowledge, module for analyse and propose the best solution and external stimulus. The framework's objective is to support human oriented knowledge ground through analysing the current user's profile.

Figure 3-1 shows a general overview of this framework as well as the correct flow of the system's events. The system described by this framework has to handle from one monitor system to a huge amount of them in profile monitoring, because the framework can require more data to complement the user's profile to get better results. On the other hand, they need to be capable of deliver the output to the users, depending on the actual user's profile and the effects of that output on the user. The module knowledge is responsible for storing all the information provided from profile monitoring (to enable learning from the previously acquired data) and must search in one ontology, in order to get all the necessary information to user's affective state evaluation.

With this information about the user, module to analyse and propose one solution can deduce the best solution for user. The system must also be capable to take advantage from previously stored data in order to refine its results to benefit the user. For this reason, it is important to store the current user's profile, the actions proposed to the user and the profile after the actions made. According to the results from this last module, the user is presented by external stimulus with the last module, which has the capability to change the user affective state.

3.1. Physiological Measurements

To deduct what the emotional state is, it was used physiological measurements. It was used the e-Health Sensor shield, which was connected to one Arduino Uno, to connect a group of physiological sensors and extract physiological data to infer the user's emotional state. This data is passed through serial port of Arduino and it was used digital pins 0 (RX) and 1 (TX) to communicate. For this reason it cannot be used the pins 0 and 1 for digital input or output.

The E-Health Sensor Shield has two limitations:

- EMG sensor and ECG cannot work simultaneously. For this reason the shield has an integrated jumper which allows to define what sensor to use;
- ECG cannot use 3 leads and simultaneously use GSR sensor. To use both sensors at same time, ECG can only use 2 leads, positive and negative leads.

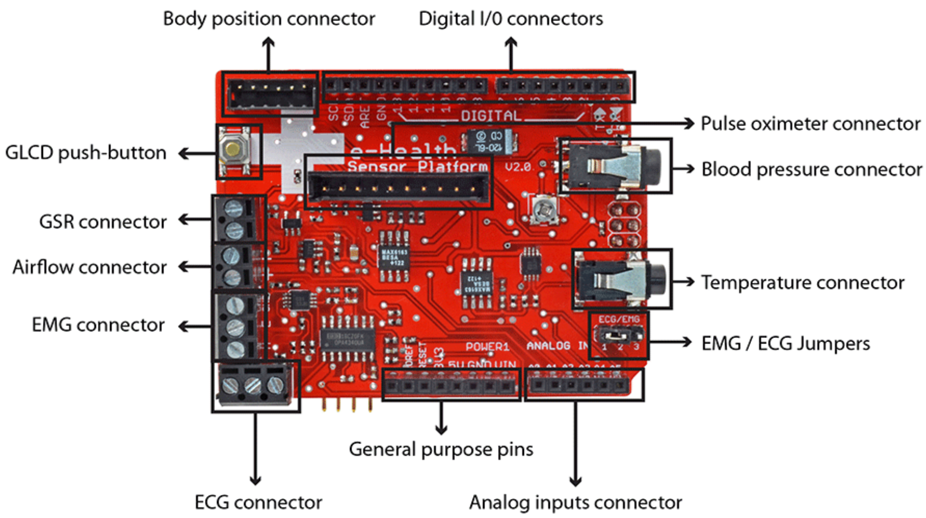


Figure 3-2 represents the e-Health shield that was used to connect the sensors. For this dissertation, it was not used the GLCD (Graphic Liquid Crystal Display) push-button, because there weren't any available to use, and it was not used Glucometer because it wasn't relevant for this dissertation.

3.1.1. Libraries

In order to get data from sensors, CookingHacks [26] gives connections of the sensors to the board and high level libraries functions which allows these functions to get data from all sensors. These libraries already have defined analog/digital input ports of the connections of each sensor and mathematical manipulations to put data in right format. All data treatment that converts analogue data into digital data of each sensor (except for SPO2 (Peripheral Capillary Oxygen Saturation) sensor) is made by components embedded on the e-Health board. To use provided libraries it is necessary to add in Arduino code the library <eHealth.h> to get the correct data from sensors. To use pulsioximeter it is necessary to use <PinChangeInt.h> library. Both these libraries must be previously installed on Arduino program.

3.1.2. Sensor functionality

For this dissertation it was available several sensors which all were tested and described on next sub-sub-chapters.

3.1.2.1. Pulse and Oxygen in Blood

Oxygen saturation is defined as measurement of amount of oxygen dissolved in blood. Pulse is the number of times the heart beats per minute (BPM).

This sensor can give the following vital parameters:

- SPO2: Quantity of oxygen's saturation on blood;
- Pulse or Heart beat rate.

This parameters are computed directly on SPO2 sensor and then passed to e-health shield through serial communication.

Table 3-1: Specifications of the Pulse Oximeter sensor

Specifications	SPO2 (%)	Pulse Rate (BPM)
Value	Digital	Digital
Range	0-100	30 - 240
Resolution	+-1	+- 1
Accuracy	+-2, from [70-100] Unspecified from [35-70]	+- 2

3.1.2.1.1. Code to get data from SPO2 sensor

As previously mentioned, this sensor needs to include <PinChangeInt.h> library in order to have one interrupt on Arduino code. This interrupt is activated when changes in this sensor' analogue port occurs. The conversion of this sensorial information is made by determine which are the active leads and converting them into numbers.

3.1.2.2. Electrocardiogram

Electrocardiogram is a diagnostic tool capable of assess the electrical and muscular functions of heart. With ECG it is possible to:

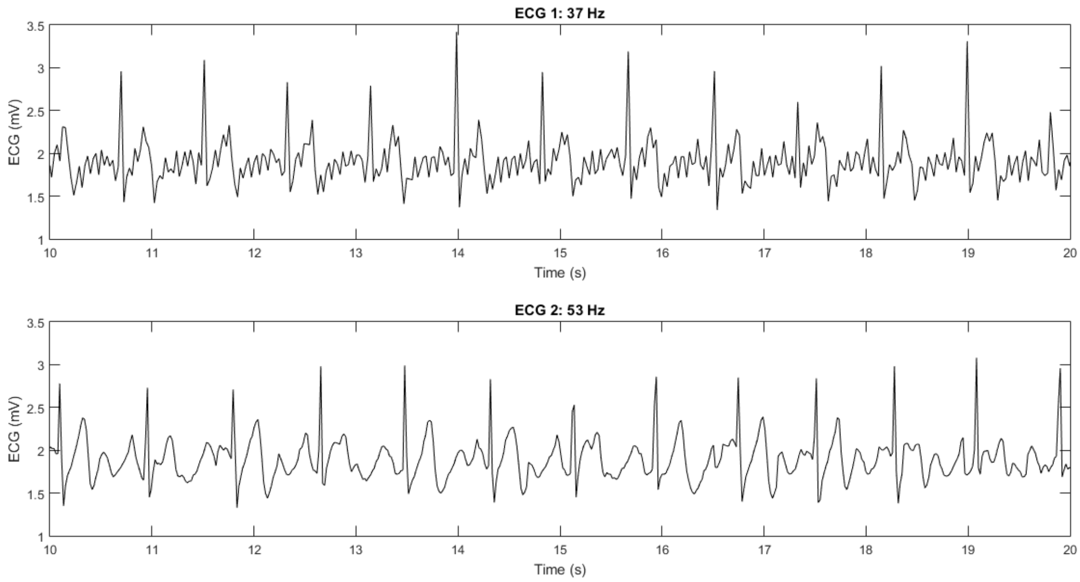
- Determinate the orientation of the heart (how it is placed) on the chest cavity;
- Detect increased thickness (hypertrophy) of the heart muscle;
- Detect damage to the various parts of the heart muscle;
- Detect an acutely impaired blood flow to the heart muscle;
- Detect patterns of abnormal electric activity that may predispose the patient to abnormal cardiac rhythm disturbances;
- Determinate the underlying rate and rhythm mechanism of the heart.

The corresponding library of ECG returns one voltage which made possible to draw one graphic of the electric activity of the heart. The ECG was recorded using 3 disposable surface electrodes placed in a configuration suggested by the manufacturer [26]):

- Negative lead: Left side, below the heart and above umbilicus;
- Positive lead: Right off the chest under the shoulder;
- Neutral lead: Left chest under the shoulder.

3.1.2.2.1. ECG frequency rate

In order to have more precise ECG signal, it was reduced the delay of the other physiological signals that are unable to use along with ECG. It was also tried to change Arduino Uno board with an Arduino Mega board. Although frequency rate improved from 37 Hz into 53 Hz, this change didn't allow the use of SPO2 sensor, because their values returned both "0" and all sensors had high noise levels. The ECG sensor, with this change, had signal distortion, which is



illustrated on Figure 3-3. Although it was important to have an ECG with higher samples per second, the equipment couldn't support higher frequencies. For this reason it was not used Arduino Mega (or Raspberry pi, which also has high frequency rates) for physiological measurements, because they did not bring any advantage.

3.1.2.2.2. *Code to get data from ECG sensor*

The ECG values are acquired directly from analogue port 0. To get accurate plots from ECG, it is necessary to determine the exact time of the measurement. To do this it was used the number of milliseconds of each measurement.

3.1.2.3. Airflow: Breathing

Airflow sensor measures breathing rate or respiratory rate for both nasal and mouth respirations. This sensor has a thermocouple sensor which has the capability to measure the difference of temperature between their two conductors. When temperature differs from the reference temperature it produces a voltage. This voltage represents the intensity of breathing. This sensor is placed on best nasal/oral thermal airflow changes.

With this sensor is possible to know:

- Breathing rate;
- The intensity of breathing.

Specifications of the sensor:

Table 3-2: Specifications of the Airflow sensor

Parameter	Value:
Sensor material	Thermocouple type K
Range	0 - 1023
Resolution	+-1º C

3.1.2.3.1. *Code to get data from Airflow sensor*

Airflow data is acquired directly from analogport 1 and its data represents the intensity of breathing. If it is used with higher frequencies rates their measurements have noise and don't have constant readings.

3.1.2.4. Body temperature

This sensor depends upon the place in the body at which the measurement is made because different parts of the body have different temperatures. The most accepted average core body temperature is 37.0ºC. In healthy adults, body temperature fluctuates about 0.5ºC throughout the day with lower temperatures in the morning and higher temperatures in the late afternoon and evening [26].

With this sensor it is possible to know:

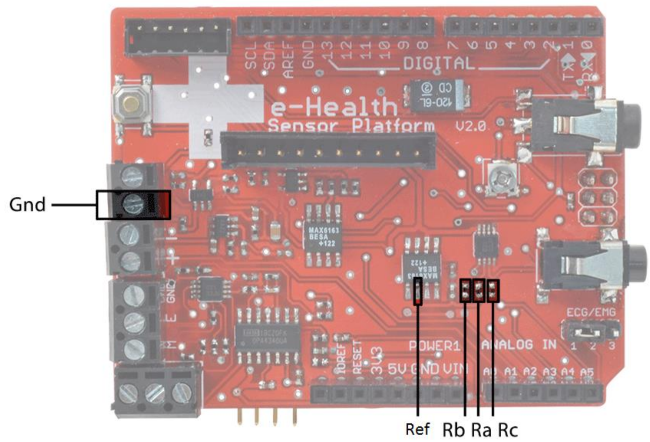


Figure 3-4: Temperature calibration sensor. To make this calibration it is necessary to know the values of the following resistors: Ref, Rb, Ra and Rc

- Skin temperature.

When using this sensor, it is actually measured a voltage. To calibrate it, it is necessary to measure the resistor values of Ra, Rb, Rc and Ref. These values are represented on Figure 3-4. These new values are placed on library file: eHealth.cpp under the function: getTemperature.

Specifications of this sensor:

Table 3-3: Specifications of temperature sensor [64]

Parameter	Value:
Sensor material	YSI400 NTC thermistor
Range (°C)	-40 : 150
Resolution (°C)	+-0.115 from 0 to 50

3.1.2.4.1. Code to get data from Temperature sensor

All data gathered from temperature sensor was acquired through the e-health library. Firstly, it is acquired the values from Arduino's analogue port 03, and accordingly to Ra, Rb, Rc and Ref resistor's values, it was calculated the correct temperature by the value of electric resistance of Wheatstone bridge formed by the resistances above.

3.1.2.4.2. Delays of temperature sensor

This sensor has a delay of reaching the correct skin temperature, if the sensor wasn't already on skin contact. The times this sensor takes to reach the correct temperature values are presented on Table 3-4.

Table 3-4: Time to reach skin temperature after the sensor is in contact with skin. Time data takes to return to initial temperature. These values were acquired after several tests.

Description	Time (s)
Reach stable temperature value after skin contact	60
Return to initial temperature without skin contact	364

3.1.2.5. Blood pressure

Blood pressure sensor gives three physiological measurements: systolic pressure (as heart beats), diastolic pressure (as the heart relaxes between beats) and heart pulse.

It is possible to know information when the measurement was made. This sensor can also give previously recorded information of:

- Systolic pressure (in mm Hg);
- Diastolic pressure (in mm Hg);
- Pulse (per min).

Specifications of blood pressure monitor:

Table 3-5: Specifications of blood pressure monitor

Parameter	Value:
Model	KD-202F
Measurement method	Oscillometric system
Measuring range	Pressure: 0-300 mm Hg
	Pulse: 30~200 p/min
Measuring accuracy	Pressure: <±3 mm Hg
Memory	80 measurements
Power source	4x AA batteries

3.1.2.5.1. *Code to get data from blood pressure monitor*

The e-Health shield only allows to request data stored from the blood pressure monitor. To do this, the shield sends to the sensor specific codes to start the communication to get information from this sensor. If there aren't any information stored on the blood pressure monitor, it returns zero number of measures. If there are measurements stored on this sensor, it sends to the e-health shield, through serial communication, the systolic and diastolic pressure as well as pulse values of each measurement stored.

3.1.2.6. Patient positions and falls

This sensor monitors five different positions: standing or sitting, supine, prone, left and right.

Table 3-6: Specifications of patient position sensor

Parameter	Value:
Accelerometer	Triple axis accelerometer

With this sensor it is possible to know:

- Position of the user.

3.1.2.6.1. *Code to get data from patient position sensor*

This sensor sends the data to the e-health shield by I2C (Inter-Integrated Circuit) communication. This data contains the accelerometer information of the 3 axis. With this, it is analysed the different axis values and it is defined the user's position. This function can be changed in order to know if the patient is moving, a functionality useful for knowing if a person is running or walking.

3.1.2.7. GSR

GSR sensor measures electrical conductance between 2 points. It is essentially a type of ohmmeter because their measures are based on the sensor's resistive value. The electrical skin resistance is based on sweat produced by human body. It is possible to observe a decrease of this value when high levels of sweating occurs [26]. The contacts of this sensor don't have polarization.

Table 3-7: Specifications of GSR sensor

Parameter	Value:
Type of sensor	2 leads

3.1.2.7.1. Sensor calibration

It is necessary to measure Condu_GSR variable of Figure 3-5. That value should be placed on eHealth.cpp library on the "getSkinResistence" function, over the conductance value.

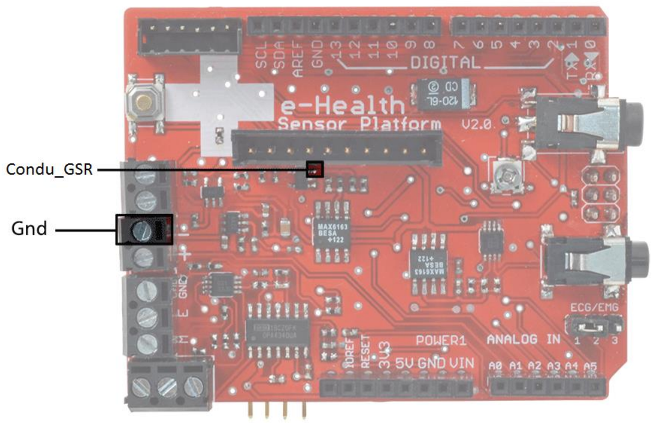


Figure 3-5: Calibration of the GSR sensor. To make the correct calibration it is necessary to measure the voltage of Condu_GSR

3.1.2.7.2. Code to get data from GSR sensor

Skin conductance, skin resistance and voltage of skin conductance values are known by the use of functions from eHealth.h library. In here, the data from this sensor is acquired by analogue port 02 and then it is performed mathematic operations, using electric resistances, to know the correct skin conductance. This value is used to get skin conductance, according to Condu_GSR voltage's value.

3.1.2.8. EMG

An EMG measures the electrical activity of muscles at rest and during contraction. It is used an instrument called electromyograph. It detects the electrical potential generated by muscle cells when these cells are electrically or neurologically activated.

This sensor measures:

- Electrical activity of one muscle, depending on the amount of activity on the selected muscle.

Table 3-8: Specifications of EMG sensor

Parameter	Value:
Type of sensor	3 leads with electrodes
Adjustable gain	EMG gain potentiometer

3.1.2.8.1. Code to get data from EMG sensor

EMG's values are acquired directly from analogue port 0.

3.1.3. E-health physiological characteristics

It is necessary to understand sensorial data to know if any sensor is not function properly or if one sensor isn't attached correctly to human body. For these reason it was made Table 3-9 to detect that errors.

Table 3-9: E-health sensorial information [26]

Sensor	Normal Values	Non-normal values	When it is not connected	When it is not attached to human body
SPO2 (%)	95 - 99	88 - 94 - hypoxic drive problem 100 - can indicate carbon monoxide poisoning	0	0
Pulse (BPM)	For a healthy male adult is around 60 [65]	0	0	0
ECG (V)	ECG signal wave	-	0 - 5	0 – 3.33
Airflow: breathing	15 - 30 breaths per minute	-	0 - 1023	0 - 1023
Body temperature (°C)	36.5 – 37.5	<35.0 – hypothermia 37.5 – 38.3 – fever or hyperthermia 40.0 – 41.5 – hyperpyrexia	Values around 31.7	Values around 31.7

Blood pressure – Systolic (mmm Hg)	90 – 119	< 90 - Hypotension 120 – 139 – Prehypertension ≥ 140 - Hypertension	Number of measures: 0	Don't interfere with data acquisition
Blood pressure – Diastolic (mm Hg)	60 – 79	< 60 – Hypotension 80 – 89 – Prehypertension ≥ 90 - Hypertension	Number of measures: 0	Don't interfere with data acquisition
Patient positions and falls	-	-	Non-defined position	1 - 5
GSR	Random numbers	-	-1	0 - 1023
EMG	Random numbers	-	Random numbers	0 - 1023

The Table 3-9 will be used in sub-section 4.1.1 on the "Data Analysis" function.

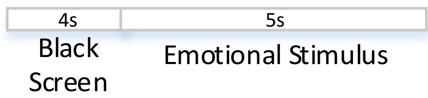
3.2. Experiment 1 - Physiological measurements

The first thing to do when using sensors is to know how they react to emotional changes. For the purpose of this experiment it was used pictures instead of music because it was only necessary to know the response of the sensors. The advantage of pictures is that they can change person's emotion for a brief period of time because the stimulus is immediate and it can get different types of intensity by showing shocking images and soft images. Music has the disadvantage of taking too much time to change an emotion and that change is progressive, a fact that is not pretended in order to understand the sensors' response.

3.2.1. Method

3.2.1.1. Material

There were chosen 19 pictures with the objective of changing one person's emotions. To do that it was selected images of babies, landscapes, couples having sex, kids with hunger, funny pictures, sad pictures and scary pictures in order to try to induce different emotions. They were put on a black background and they changed between pictures in 5 seconds with a black background with 4 seconds. To intensify the scary picture it was added a screaming sound. This procedure was identical made on [66], where each requested emotion was separated by a dark screen for 2 to 3 seconds and they only wanted to represent positive, negative and neutral emotional states. Although these researchers used EEG, GSR, BVP and Respiration sensors for their experiment, they verify changes on signals on different emotions.



There were used the following sensors: ECG, GSR, respiration, body skin temperature and SPO2.

3.2.1.2. Participants

This test was made with 2 participants and neither of them knew the content of the images. They only knew that it was going to perform a physiological test with several pictures. They were both right handed, 1 male with age 24 and 1 female with age 23.

3.2.1.3. Apparatus

The group of pictures were shown in one video clip. The data, from all sensors, were acquired by Arduino, through the developed system, with "Test Sensors" option. Since it was known the experiment time, which was 2 min and 51 secs, this time was referenced in the system in order to have precise data acquirement, which is important to see the differences between pictures.

3.2.1.4. Procedure

The video was played on same computer of the developed system program. Firstly, the participant placed the ECG sensor and with the system tool "Test sensor" it was observed the sensorial data of ECG sensor. If the acquired data could represent a legit ECG signal, the ECG sensor was used for the experiment. If not, GSR sensor was used instead, and tested similarly as ECG sensor. Secondly, it was observed if the other sensors had correct signals and if the temperature sensor had stable values. Finally, it was performed the experiment 1 through system tool 'Test sensor'. At the end of the experiment, it was saved all physiological signals. To see the video clip with the selected pictures, if the user were at a public place he used headphones, if not, he listened to the video through computer's speakers.

3.2.1.5. Results

This experiment was performed in order to know if it was possible to identify physiological changes experienced by different emotions. Figure 3-7was one result from this experiment from one female subject. The ECG and GSR were not used because they were mal function and for that reason they did not gave useful emotional information. This malfunction was reported to the e-Health shield's manufactures and they admitted that this product had problems with GSR and ECG sensors.

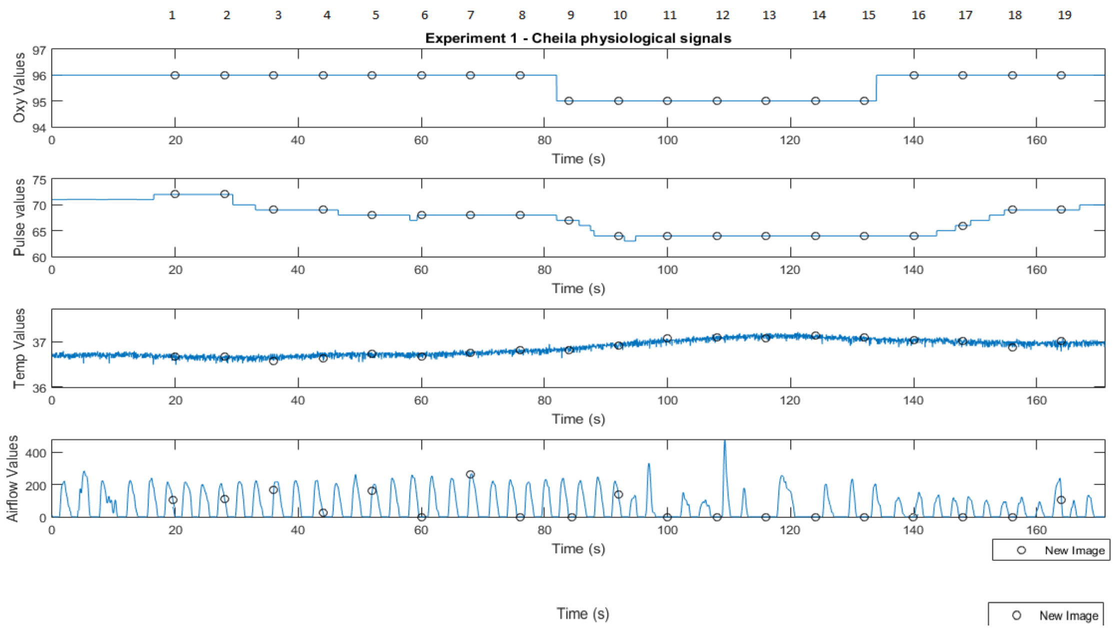


Figure 3-7: Physiological signals from 1 subject with Experiment 1. It is represented four physiological measurements in their correspondent times. The used sensors were: Oxygen in blood, pulse, skin temperature and airflow. On each signal it is represented the exact moment and picture number. All pictures are illustrated on annexes –sub-section 7.1

As can be noticed by Figure 3-7, it is empirically possible to identify changes in the 4 tested sensors. Oxy measurement, which refers to the percentage of oxygen in blood, had a fall after one happy picture and returned to previously value after one baby's picture, in 2 min and 14 seconds. Pulse sensor also changed during all experiment, except when it was shown the scary picture along with a scream sound, where HR stabilised during 53 seconds. Temperature and airflow values had small fluctuations, except when it was shown the scary picture and pictures with sexual content, where these sensors had enormous variations.

With this experiment it is possible to conclude that this four sensors change with emotional induction and for that reason they can be used in order to detect features to make emotional deductions. This results will be used in order to make one system which uses these physiological sensors in order to identify the emotional state of one user. The implementation of this system will be analysed on the following chapter.

4

4. Developed Architecture

In this section it is described the proposed architecture able to be used in applications that intend to analyse the user's profile.

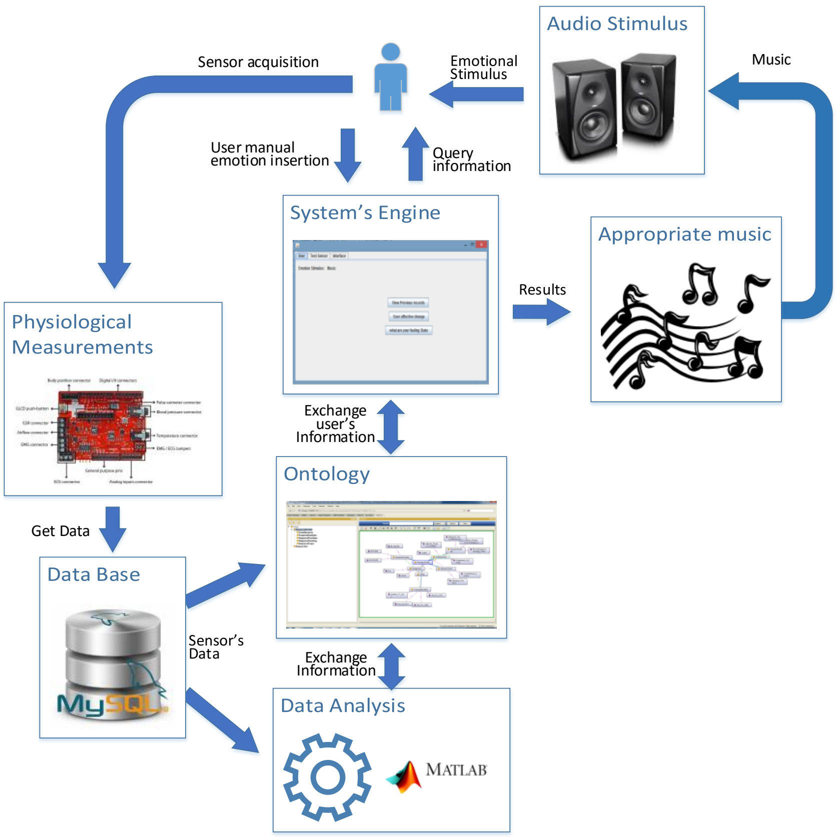


Figure 4-1: System Architecture

4.1. System Architecture

The developed system is based on the framework proposed in the before section. Such system main objective is to suggest music accordingly to the identified emotional states so that a comfortable feeling can be induced to its user. The system architecture is represented on Figure 4-1, which is composed by seven modules: (i) physiological measurements (data capturing), (ii) database (with MySQL query language), (iii) system's engine, (iv) ontology, (v) data analysis (with the MATLAB software), (vi) choose the appropriate music and (vii) audio stimulus. The module physiological measurements is where it is possible to constantly receive data from physiological sensors. The data acquired from physiological sensors in this module is saved in a database in the module database. The module system's engine is responsible for receiving information from the user, regarding its initial/final emotional states, and for sending the most appropriate music to the most appropriate module based on profiles saved in module ontology. These profiles are created from each user's pattern, which accomplishes data analysis with module data analysis. This data analysis encloses specific filters applied above to the physiological measurements to obtain specific information as identification or recognition of a specific emotion.

The list of users, the initial/final emotional state, the music list, as well the one chosen is saved in the ontology using the Java framework Apache Jena [67], as it allows the management of the ontology. As it can specify beforehand the necessary queries, and be efficient accessing the information to obtain, as an example, the appropriate music for a specific profile it was used SPARQL language. Finally, due to its countless useful tools as signal filters, Matlab was used for data signal analysis.

4.1.1. Module (i) - physiological measurements

All physiological measurements are acquired by module (i), through one Arduino UNO, which has attached one e-Health shield that connects all biometrical sensors. The raw values from each sensor are automatically calculated by the shield and returned by the correspondent port from the Arduino. The Arduino uses serial communication and in order to increase its frequency rate, because it is necessary to differentiate small changes in physiological signals, the baud rate was defined as 115 200 beat per second. With this baud rate, the shield doesn't have enough time to get the correct sensorial data from the sensors. For that reason it was added small values of delay, enough for the shield to have time for update their values in order to get the correct physiological data.

The Arduino code is divided into 4 parts:

- Start sending sensorial data: The Arduino only starts to send sensorial data after it receives the 'C' character. If the ECGs values are being measured, the sample rate is 50 Hz, if not the sample rate is 32 Hz. The drawbacks of having higher frequency rates are the addition of noise in raw data and problems in RXTX communication (since it sometimes sends repeated information);
- Data Acquisition: It gets sensorial information either through Arduino analogue ports or library functions provided by the e-Health shield. It also computes the milliseconds from the beginning of the measurement, in order to know the precise time of the data acquisition;
- Data Treatment: Verify the veracity of the data. This part of the Arduino code was based on Table 3-9. The oxygen's values only have the range of 88 to 100%, pulse's values of 0 to 200 BPM, air's values above 0 and body temperature of 34 to 42ºC. These values were defined according to real physiological values, sensor's specifications and maximum values from previously tests with these sensors. This data treatment was done because it can induce wrong conclusions about the emotional state of the user;
- Stop sending sensorial data: Every time the Arduino sends sensorial data through serial communication, it also verifies if it has received the 'F' character. It this situation occurs, the communication ends.

4.1.2. Module (ii) – database

To store and access previously data acquired, it was used one database in order to store all data acquired by Arduino. Each sensor has one correspondent table on the database.

MySQL [68] was the chosen database because it is one database program that is easy to manipulate information using Netbeans IDE [69], which connects JAVA program to MySQL server directly from it.

There are 4 important type-queries that were used for manipulating the data base:

- Select: It was used for acquiring data from each sensor and for saving them into one file. The type of file used for saving the tables was ".txt" because it was easier to see changes on the values without any external program and it is also compatible with Matlab program. Time and its correspondent data values were saved in separate lines, enclosed by '"' and terminated by ',';
- Insert: Save sensorial information of each active sensor into the correspondent table. In this type of queries it is important to insert different time values because they are primary key of each sensor's table;
- Delete: Erase the content of each table;
- Load data: Load the information from one file into the correspondent table.

The database used for storing data from physiological measurements is composed by 6 tables, each one of them corresponds to one sensor. Each table has two different columns, one for time of measurement, and the other column has the measurement of the correspondent sensor. Only SPO2 sensor has two columns for data measurement, because this sensor gives two different physiological data.

4.1.3. Module (iii) - system's engine

It corresponds to user's interface. In here it is possible to define the sensors to use with, visualise previously stored information, make physiological measurements and get signal characteristics from physiological signals. It is divided into the following sub-sections.

4.1.3.1. Test Sensor

It is possible to verify the output of each sensor through their plot, with raw value on the Y-axis and time (in seconds) on the X-axis. It has the option to store current values of each sensor as well as visualise previously saved signals. If the user wants to specify the time of the test, he has that option in order to have better control on that test.

4.1.3.2. Measurements

This part of the system is used for analysing the effects the music has on the physiological state of the user. The procedure is:

- User chooses which sensors he wants to acquire their physiological signals;
- User defines what its current emotion is (initial emotion);
- User chooses or add one music he intends to listen accordingly to the emotion he felt while listen to that music (this physiological test can be done with musical time specification, in order to have better control on the results of this test);
- After the user listened to the music, he defines what his current emotion is (final emotion);
- Finally, having all components that characterize this test, all information regarding this test is saved on the ontology and the physiological measurements are saved into one '.txt' file.

4.1.3.3. Experiment

This part of the system is used to make quick comparisons between different music and its physiological changes. To do this, there are chosen a group of music from the system and each music will be played after one baseline period. Since this part of the program intends to be for scientific use, it is possible to change the times from baseline and music play times. At beginning and ending of music, the user is asked to define his current emotion.

It was used one baseline time in order to make people be at their neutral state and be easier to observe physiological changes while the user is subjected to different emotional stimulus [33]. Although for this system the baseline is not used, this periods of time are saved along with all physiological experiment.

With this procedure it is possible to have physiological signals with physiological changes that happens when different music play and change the emotional state of the user.

4.1.3.4. Music suggestion

According to the user's emotional state the system uses the ontology in order to suggest the most appropriate music, accordingly to its emotional state. It has the option to define the emotional state though a previously trained machine learning or can be defined manually. This functionality is explored on section 5.2 - Scenario description and this architecture is defined as module (vi);

4.1.3.5. Add Individual Info

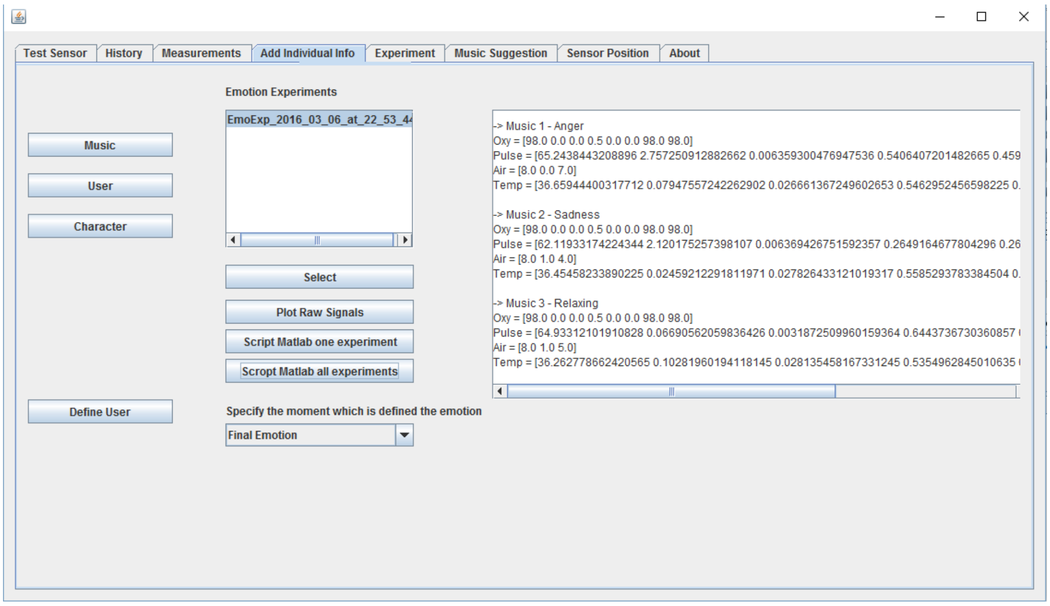
All information of one music, new user and compute physiological' characteristics of each sensor used are stored on module (iv) – ontology. These characteristics are computed through module (vi). There is also the option to save all characteristics into one file in order to use these characteristics on a machine learning (for instance, with Matlab program). The characteristics can be computed using either initial emotion, final emotion or the emotion which the user has defined to categorize the music he has listened. Figure 4-2 is one example of this functionality.

4.1.3.6. History

It shows all information stored in the system. All users, their personal info, emotional records and emotional experiments can be visualised in this part of the interface.

4.1.3.7. Sensor position

This options informs the user about the position of each sensor.



4.1.3.8. Connections with the other components of the architecture

This module connects the majority parts of the system in it. It connects with:

- Arduino: it is made by serial communication. At the beginning of the program the communication is made with Arduino, but the system only receives/stops receiving data when the system wants to. To establish the connection, it is necessary to know the port where the Arduino is communicating and defining the baud rate of serial communication;
- Database. The connection is made by JDBC (Java Database Connectivity) driver that connects the Java program with one MySQL database. It is made at the beginning of the program, which make possible to perform SQL (Structured Query Language) operations directly from Java. It also makes updates, receives or deletes data from

the database that was created. To establish connection to the database, it is necessary to define the location, user name and password of it;

- Ontology. The connection is only made when it is necessary to access its information;
- Matlab. The connection is only made when it is necessary to perform data analysis.

The connection with Arduino and Database was made at the beginning of the program because they are crucial elements of this system that should ensure their functionality before making measurements of the physiological data.

4.1.4. Module (iv) – ontology

The ontology module is where all the important information is saved which is important to create new knowledge. The ontology structure was created with Protégé 3.5. Although this version is outdated, 3.5 Protégé version was chosen because its interface is more intuitive in order to create data properties and object properties. Besides that, new versions of Protégé doesn't support access for ontology via RDF(S) files [70]. The ontology have the characteristics:

- Classes;
- Object properties;
- Datatype properties;
- Instances.

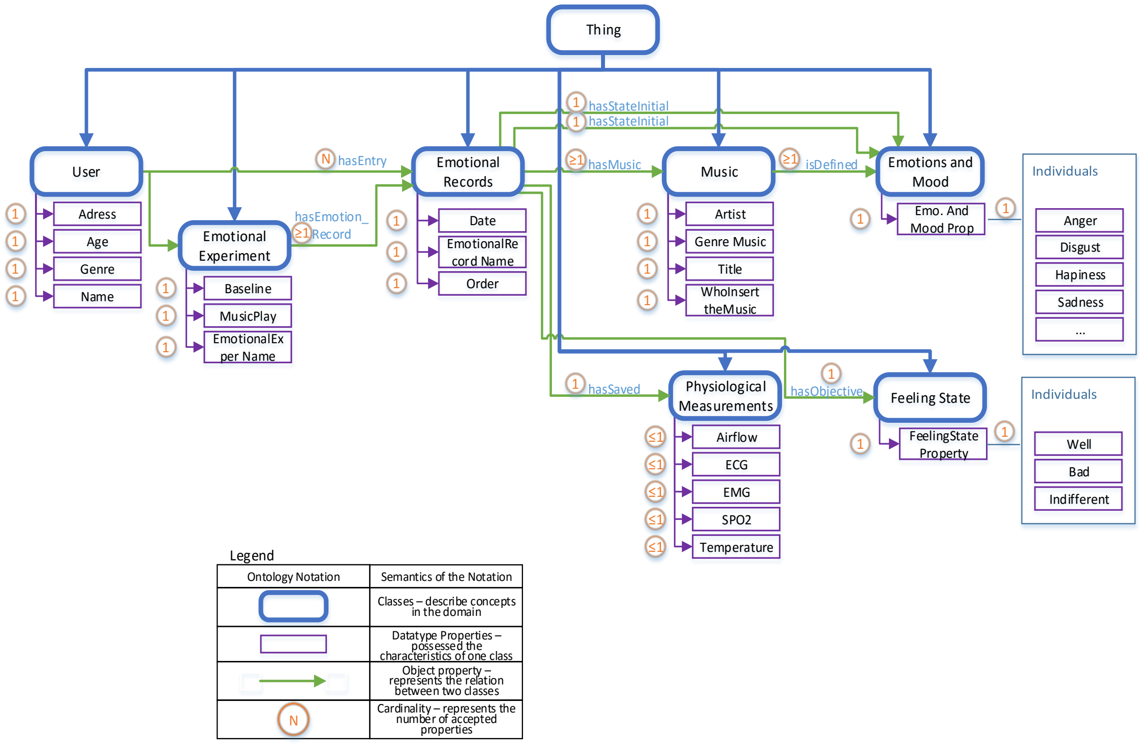
It was defined restrictions (cardinality) to the model so that some parameters cannot have more than a defined number of elements. All datatype properties also have defined the range that they can have, i.e. if the datatype is one string, integer, data type or can only be defined values.

The Java framework Apache Jena [67] was chosen to save new information on the ontology, because it allows to save new entries on the ontology and it possesses libraries (OWL-API) which are very identical with protégé. To make the deduction of all information from the ontology, it was used SPARQL language, because it can specify beforehand the queries that are necessary and it takes almost no time to access the information stored on the RDF file. This RDF file is where it is described the entire ontology from module and its stored individuals.

4.1.4.1. Ontology Model

The ontology model in this research has some main classes which are represented in Figure 4-3. They are:

- User: represents personal information about the user. It could also contain all emotional records as well as emotional experiments performed by user;
- Emotional Records: to perform an analysis for music listening, it was relevant for this research saving the initial and final emotion the user felt while listening each music, in order to analyse, individually, what types of music that can change each emotional state. For this reason this class contains each event data, thus it links all the information about the emotional records of one user, as initial and final emotion, and the information of music that the user was listening;
- Emotional Experiment: For this research it was important to acquire several music that induce different emotions to each user. For this reason this class links each emotional record to the user. This class also has the music played on each emotional experiment and their baseline and music play time;



- Music: contains all the information of each music. Since the emotion felt is different for the same music by each person, each music' individual have the name of whom inserted the music;
- Physiological Measurements: contains the physiological measurements of the user, while listening a specific music;
- Feeling State: defines the different feeling states of the user;
- Emotion and Mood: has the description of different emotions and moods.

4.1.5. Module (v) - data analysis

For data analysis it was chosen the Matlab program [71] because it is a program that contains countless useful tools for data signals and some functions can be exported to be used directly on Java. It is used for:

- Signal analysis: it uses raw physiological data to characterize, through features, each sensor signal. This analysis will be explored on section - 5.1;

- Machine Learning: it defines the user's emotional state based on the features extracted by each physiological signal. This functionality will be described on sub-section 5.2.2.1.

To use all created functions of Matlab into this architecture, it was used Matlab tool: "Aplication Compiler". This tool converts Matlab code into libraries which can be used with Java. This Matlab code must be made in form of one function. It also needs to specify the number of inputs as well as the number of outputs. All data from physiological signals are converted into numeric arrays of double-precision.

4.1.6. Module (vi) - choose the appropriate music

After each physiological signal be analysed and knowing what are the features that are relevant to defining the physiological state of the user, it is possible for the system to choose better music (as well as the music to avoid), due to the fact that the user could have reacted in a bad way with a certain music containing a certain emotion.

4.1.7. Module (vii) - audio stimulus

This module is responsible for playing the music chosen by module (vi).

4.2. System Description

Since this system was developed in order to be used by other researchers, under sub-sub-sections 7.2.1 and 7.2.2 there will be two different guides that are useful in order to use this system.

5

5. Use Cases and Analys of Results

The proposed system can be used in different applications, as in evaluating attention in students or trainees. It could help to identify the type of music to be integrated in eLearning materials to potentiate trainees' attention. Other similar applications could be applied to industry as in trying offering better working environments to workers in such a way to increase their efficiency accomplishing their tasks. However, the main purpose of this system is not to be a product to any people but a prototype to analysts/researchers to facilitate their emotional and physiological analysis, which results/conclusions would potentiate better environments or feelings to people.

The presented research work focus on musical stimulus, using different user's profiles, where each user label each music with the emotion he/she felt while listening to it. This section is going to describe the possible scenarios that one system like this could have and the necessary analysis of the physiological signals that it is necessary the make in order to build one system which responds to the research question presented above.

5.1. Data Analysis

A signal is any function related to a physical phenomenon and has information about it. It can be continuous or discreet. To analyse and compare signals, it was used statistical information of the signals as well as the comparison through the normalization of it. The normalization is very used to compare signals between different subjects, on different days and different parameters (position of the electrodes, different skin conductivity and skin temperature make different signals for different measurements).

In the following formulas, the symbol X designates the raw signal values from each physiological sensor and $\tilde{X}$ is the normalized value of X.

For the signal normalization it was used the following formula [72]. If max value was equal to min value, their normalization value was defined as 0.5.

$$\overline{Norm(k)} = \frac{signal(k) - \min(signal)}{\max(signal) - \min(signal)} \quad \textbf{(5-1)}$$

5.1.1. Features that can be extracted through physiological signals and used in emotion deduction

The following table is a summary of features that other researchers used for physiological signals analysis, in order to deduct emotion from them.

Table 5-1: Summary of features acquired from physiological signals by other researchers

Features	Oxy	Pulse	ECG	Resp	Temp	GSR	EMG
Filter	-	Hanning Window [73]	-	median [74]	-	median [74]; Hanning Window [73]	median [74]
Mean of the raw signals	-	[74][73]	-	average chest expansion [72][66] [73]	skin temperature variation [72][25]	estimate of general arousal level [66] [73]	[74] [73]
SD of the raw signals	-	estimations of HRV [66] [73]; average acceleration/deceleration [73]	-	variation of the respiration signal [72] [73][66]	[72]	[73]	[73]

Means of the absolute values of the first differences of the raw signals	-	estimations of HRV [74][66]	-	variation of the respiration signal [72] [73][66]	[72] [73]	average GSR variation [73][66];	[73]
Normalize physiological signals (mean, variance and first forward difference)	-	using a global minimum and maximum [34] [23]	-	mean and variance [74]; [72] [73]	mean and variance [74]; [72] [73]	using a global minimum and maximum [34] [23] [74] [73]; account for baseline fluctuations through all emotions of that day [73]	$EMG_{smiling}$ and $EMG_{frowing}$ - using a global minimum and maximum [34] [23]; [74] [73]
R-Peak detection	-	-	RR interval, HRV [25]	-	-	-	-
Maximum values	-	-	-	-	skin temperature variation [25]	-	-
PSD	-	-	using HRV frequency band [25] [75]	last 2048 points of data [74][73]	-	-	-

5.1.2. Signal processing

To extract features from the bio-signals, it was used a common set of features values which are processed and used for the raw signal's classification. These common features are:

- Mean of raw and normalized signals. Vector of mean values over a specific period of time. With this vector, it is possible to distinguish between phasic, fast changes and tonic, slow moving components in the analysed signal [35]. The formulas [74] that were used in the Matlab function are:

$$\mu_X = \frac{1}{K} \times \sum_{k=1}^{K} X_k \quad \textbf{(5-2)}$$

$$\tilde{\mu}_X = \frac{\mathbf{1}}{\boldsymbol{K}} \times \sum_{\boldsymbol{k=1}}^{\boldsymbol{K}} \widetilde{\boldsymbol{X}}_{\boldsymbol{k}}$$

- SD of the signal. It can represent the activity and changes of the signal's variation. The formulas that were used in the Matlab function are:

$$\sigma_X = \sqrt{\frac{1}{K-1} \sum_{k=1}^{K} \{X_k - \mu_X\}^2} \quad \textbf{(5-4)}$$

$$\tilde{\sigma}_X = \sqrt{\frac{1}{K-1} \sum_{k=1}^{K} \{\tilde{X}_k - \tilde{\mu}_X\}^2}$$

- Means of the absolute values of the first differences of the raw signals. They approximates a gradient [73] and they were used in the Matlab function with the formula:

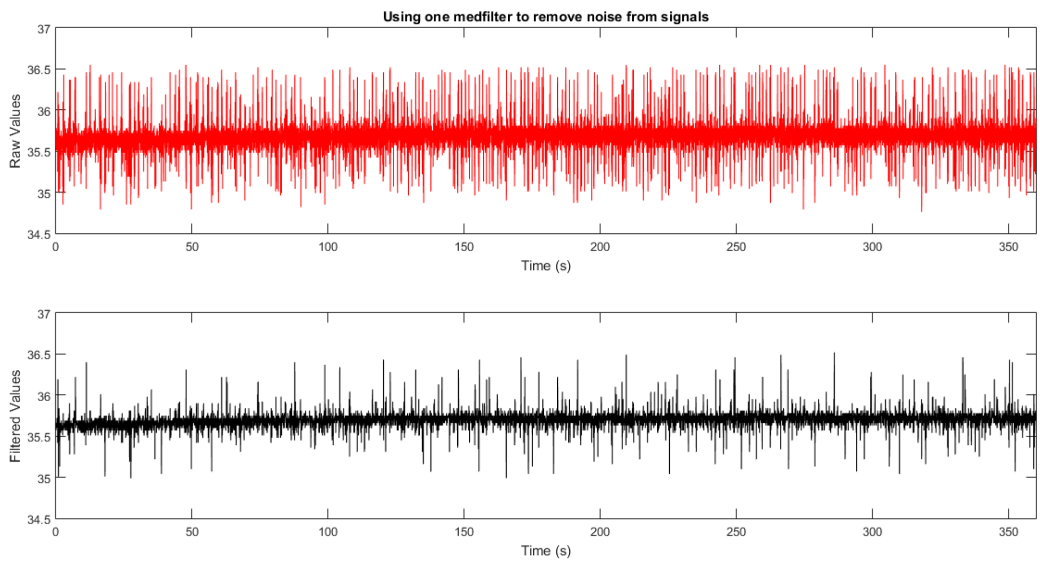
$$\delta_X = \frac{1}{K-1} \sum_{k=1}^{K-1} |X_{k+1} - X_k| \quad \textbf{(5-6)}$$

$$\tilde{\sigma}_X = \sqrt{\frac{1}{K-1} \sum_{k=1}^{K} \{\tilde{X}_k - \tilde{\mu}_X\}^2} \quad \textbf{(5-7)}$$

The signal measurements used on the developed system, for emotion recognition, suffered from various types of noise. For that reason, some signals were smoothed or subjected to filters.

5.1.2.1. Median Filter

As some physiological signals have noise, it was applied a median filter on it, using Matlab function "medfilt1" to remove the major noise from the signal. Other researchers [74] used Hanning window with the Matlab command "hanning" with a convolution of 25 sec to smooth the signal. In this system analysis the median filter was chosen because it was easier to implement and also for the signals that were filtered, the median filter made the pretended results. The difference between one raw signal and a filtered signal can be seen on Figure 5-1.

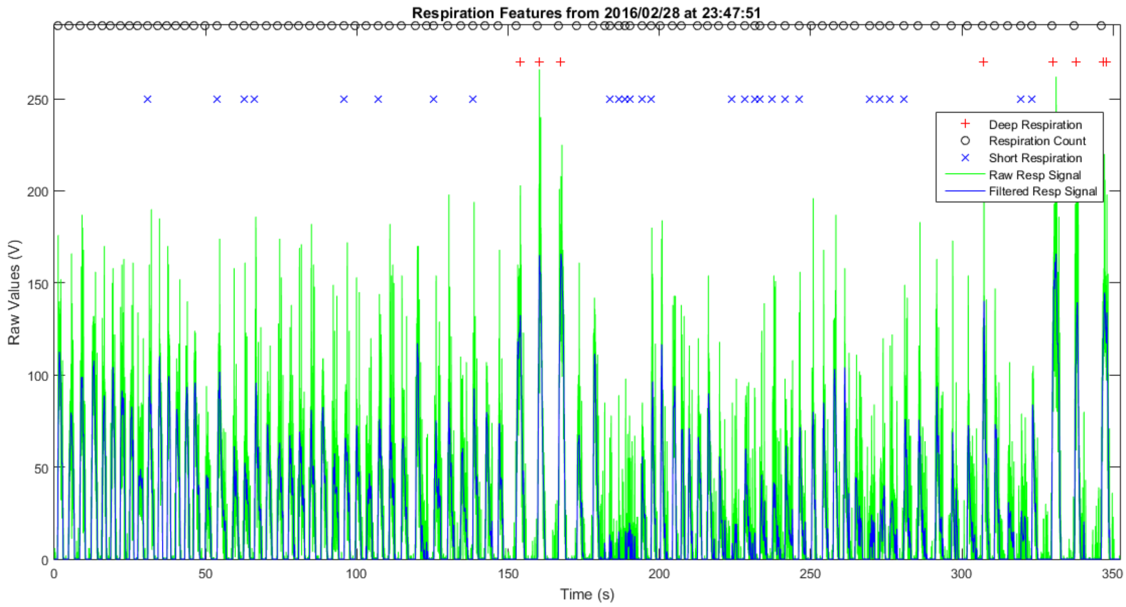


5.1.2.2. Respiration signals

The used sensor is very sensible to temperature changing and this fact results on signals with unwanted peaks and line noise, which must be treated in order to not induce wrong features.

The raw signal is first passed through a Savitzky-Golay filter to remove, not only the extreme values, but also to smooth the signal. The number of samples parameter was 15 and the polynomial order parameter was 3. These parameters were chosen accordingly to the best results observed on several tests.

To isolate the breathing moment, it was removed the values above a threshold value, that was chosen according to the sensor's data. The soft breathing had values around 25 units and for that reason the threshold value was defined as 10 units. To have a more continuous airflow signal, it was filtered again with a Sa-



vitzky-Golay filter, but this time with a smoother filter, with a number of samples parameter 17 and the polynomial order parameter was 3. These parameters were chosen accordingly to the best results observed on several tests.

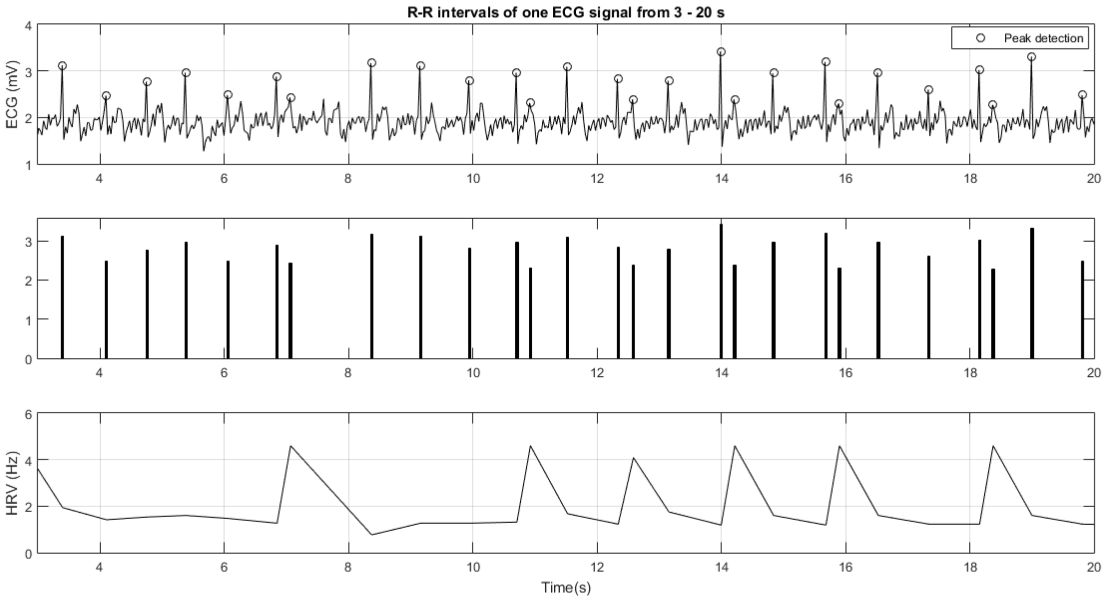
The respiratory rate feature was based when the signal had value 7 units or higher, excluding the values which were closer than 1.2 seconds. The 1.2 seconds value was chosen because inspire and expire times usually have higher values. The threshold 7 was chosen because the Savitzky-Golay filter usually decrease values.

It was calculated two other features, the number of deep breaths, that were defined by all breathings that were superior to maximum value plus one weight ($\frac{3}{4}$ of the max respiratory signal value), and the number of short breathings ($\frac{3}{8}$ of the max respiratory signal value). This parameters were defined accordingly to several respiratory signals and comparing its results.

5.1.2.3. ECG signals

ECG signals are often quoted to be from 0.05 to 40 or 100 Hz although information does exists beyond these limits [65]. Although it is important for analysing ECG signals to remove noise from this signals, by the application of one highpass band filter and one low pass filter, these filters were not applied because the sampling rate was too low, and the application of filters on ECG signals would compromise the information provided by ECG.

HRV was detected with one script based on Matlab example [76], which first detects the ECG peaks and then the RR intervals. The ECG peaks were calculated through Matlab code: “findpeaks”, with information of ECG frequency rate, which is computed at beginning of script, and Minimum peak prominence, which was defined according to best peak detection. Figure 5-3 is one example of R-R interval detection. Due to low frequency rate, ECG is not perfect and for that reason the R-R detection also has errors, which can be noticed by absences of beat that occasionally occurred.



PSD was computed through Matlab algorithm “pwelch”. It was used an estimation of PSD using Welch’s averaged, modified periodogram method [74].

The HRV was also used to compute signal’s mean, SD and the mean of the absolute values of the first differences.

5.1.2.4. All used features

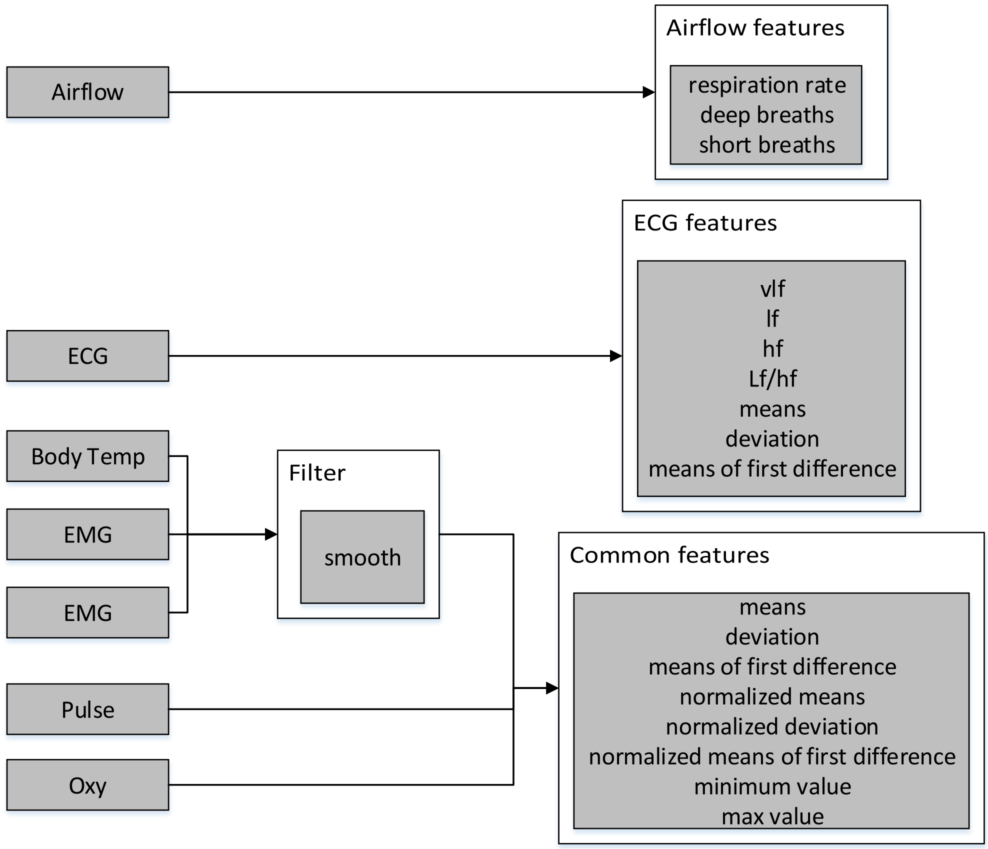


Figure 5-4 summarises all features that were extracted by each physiological measurement in this dissertation. They were based on previously features extracted by other researches, which are defined on Table 5-1. The airflow characteristics were pointed during the state of the art and since they could be useful they were used as physiological features.

With these features it is possible to characterise each signal with one specific emotion.

5.1.2.5. Feature Selection

All features were based on signal analysis aspect exclusively, without any preliminary information on which physiological pattern they might be correlated with emotional episodes. For this reason, there may exist garbage features within the computed features as they could be irrelevant for emotion differentiation. In this system, this type of selection was not made because it was used few features from few sensors, but if this fact changed, it could be used, for instance, analysis of Variance (ANOVA). This analysis is a statistical method which is used in order to decide if a feature shows significant difference between two or more other features.

5.1.3. Machine learning

"Essentially, all models are wrong, but some are useful" – George Box. This sentence means that all models are approximations based on several assumptions. Machine learning models can explain complex relations of data and to find the correct model it is necessary to find useful models for the task. In this system it was used one classifier in order to create one model that could represent emotional states with physiological features. To do this, it was used a set of training examples to predict classes, which are the emotional states. The most common classifiers for machine learning are:

- Decision Tree Classifier: it uses a recursive tree-like structure with a number of nodes and edges. The starting node is the root of the classifier. Each node corresponds to a test of one input feature and the branches that emerge from that node are test result values that can be true or false. The terminal nodes represent the value of the decision that will be returned [77];
- Support Vector Machines (SVM): a non-linear function is learned by data vectors and mapped into a feature space. It has the advantage to use convex optimization which guarantees that the optimal solution is found. It is used a loss function to weight the actual error of the point with respect to the distance from the correct prediction [13];
- K-Nearest Neighbour: this algorithm finds the similarities between the test instance and the training instance, among their k-nearest neighbours [77].

In emotion recognition area some researchers used machine learning to predict emotion. Some of them are represented on Table 5-2.

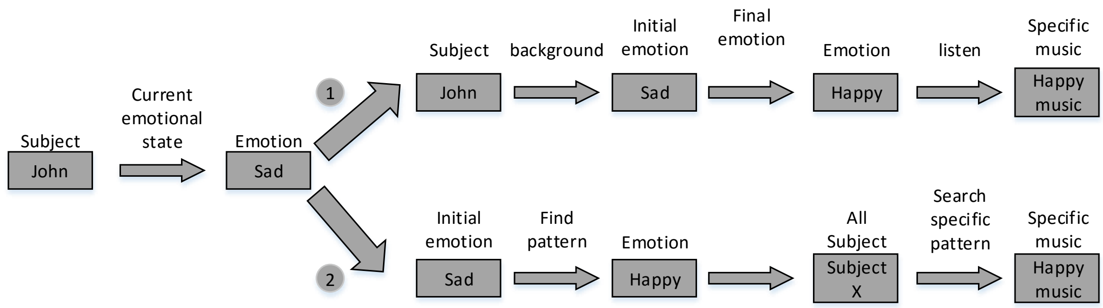
Table 5-2: Researches regarding machine learning with physiological signals

Re-searcher	Selection	Classifier	Number features	Number emotions	Feature comparison	Training, test and validation numbers	Results (%)
Haag et. al [35]	None	Neural Net	13	-	Normalized all features into the range of [0,1]	700 – 150 - 150	Arousal – 96.58 Valence – 89.93
Picard et. al [41]	MAP	SFFS with FP	40	8	Data is Gaussian – class with the highest posterior probability	2000 to 5000 samples per emotions (8)	81
Broel et. al [33]	ANOVA	k-nearest neighbours, SVM and neural network	12	4	Lagrange multipliers to now the variance of each component and data inspection through visualization of each emotion differences	24-21-21	61.31
Wang et. al [78]	GA	SVM	Not mentioned	7	Normalizing the training dataset	150 – 70 -70	95

Table 5-2 is one example that to make good classifiers, it is necessary a large number of training, test and validation data. The lowest success result of this table also has the lowest number of these values.

5.2. Scenario description

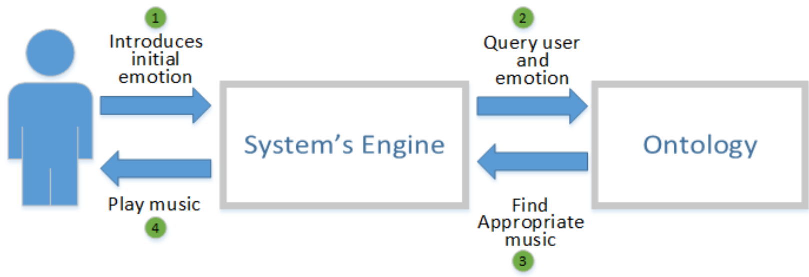
To understand the usability of this system, it was developed three different scenarios with the objective of suggesting the most suitable music accordingly to



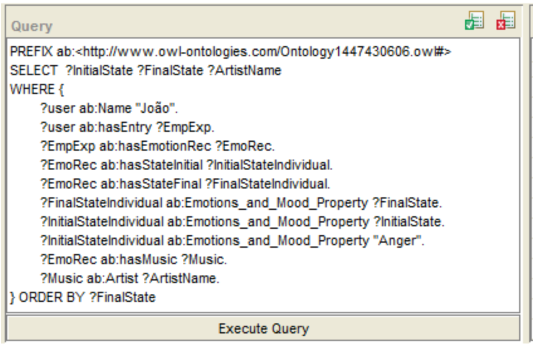
the current assessed feeling state in order to make the user to feel better (i.e. feeling good). To do this task, it is used the developed ontology where it is possible to acquire new knowledge from all information from it. Figure 5-5 illustrates this fact. On the ontology there is all user's profiles with their personal music descriptions and several data experiments and data records, which all have one musical stimulus and one initial and final emotional state felt by this stimulus. With reasoning from the developed ontology, it is very easy and quick to acquire knowledge from it. During this section Figure 5-5 will be described accordingly to the scenario.

5.2.1. Scenario 1

In a first scenario, Figure 5-6, the user introduces its initial emotional state, and accordingly to it, the system will suggest the most appropriate music. This suggestion is made accordingly to records existent in the database related to past use patterns, which comes from various emotion the user defined he was feeling while listening different music.



In order to know all previously emotions felt by each user and define the best music according to user's emotional state, it is used Figure 5-5 with path number 1. The most appropriate music is chosen from all physiological measurements the user made with this system and accordingly to its initial emotion. On Figure 5-7-A is demonstrated how to find the most appropriate music with one SPARQL query which is necessary to define the user name and its current emotion. Part of this search is presented on Figure 5-7-B with some results of the defined query. On last figure it is possible to identify different reactions for the same user and initial state. This results depend on the usability the system had in order to have more data. If the user had few physiological measurements, the search for the most appropriate music will be redundant and can give wrong music with wrong final state. Once again, this is only a suggestion based only on information saved on the ontology. Accordingly to the final emotion which the user intends to be in, the system will suggest one music.



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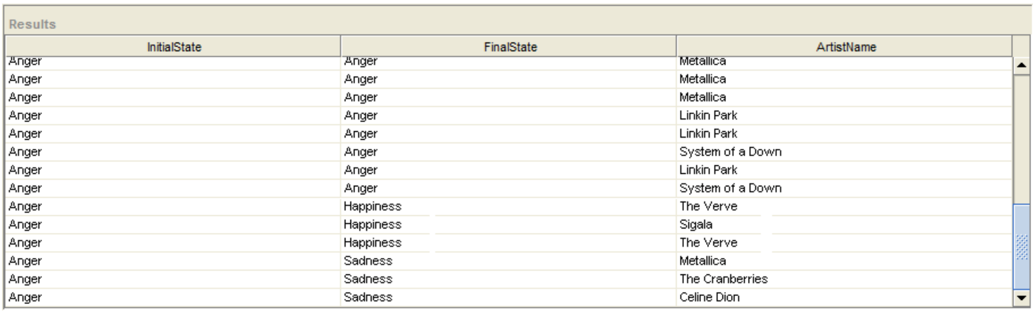

Results

InitialState	FinalState	ArtistName
Anger	Anger	Metallica
Anger	Anger	Metallica
Anger	Anger	Metallica
Anger	Anger	Linkin Park
Anger	Anger	Linkin Park
Anger	Anger	System of a Down
Anger	Anger	Linkin Park
Anger	Anger	System of a Down
Anger	Happiness	The Verve
Anger	Happiness	Sigala
Anger	Happiness	The Verve
Anger	Sadness	Metallica
Anger	Sadness	The Cranberries
Anger	Sadness	Celine Dion

B

5.2.2. Scenario 2

In the second scenario, Figure 5-8, it is gathered physiological measurements from the user to automatically determine his feeling state. Based on data analysis over such measurements, the system suggests the most appropriate music also based in past pattern information existent in the ontology. This scenario represents a conceptual experiment using sensors that can be used unobtrusively as soon as its technology integrates such sensors in small wearables. With results from Experiment 2 – Training Machine Learning – section 5.2.2.1, it is possible to deduct the user emotional state if it is made some measurements, in order to train one model. In a real scenario, this training can be made at the end of the day, where each user, connected to several sensors, listens to different music and define its emotional state.

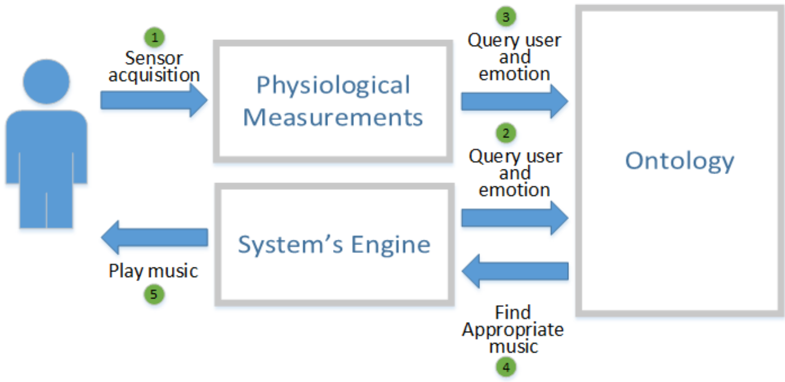
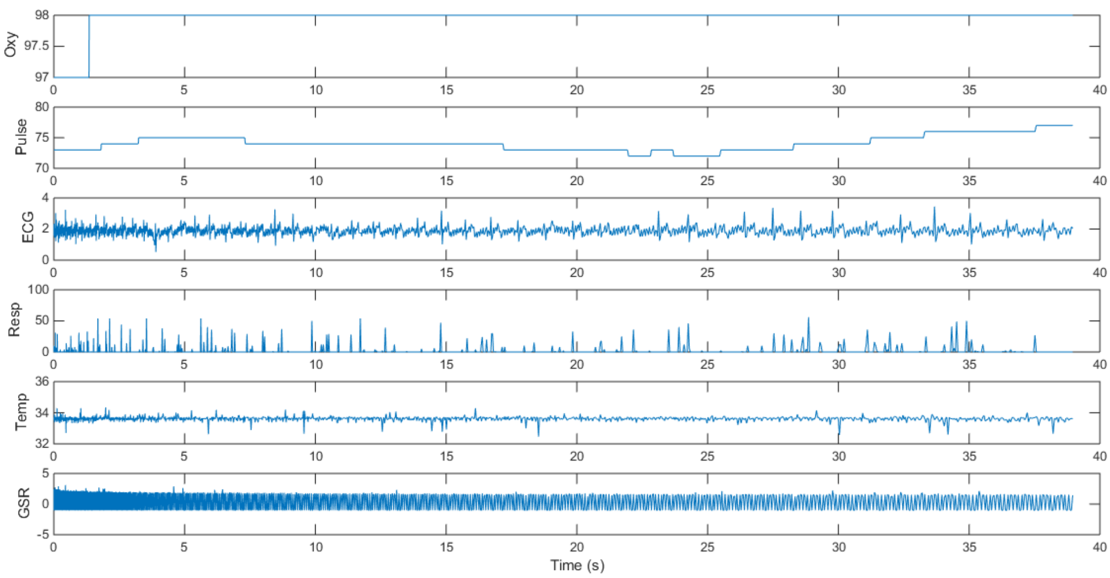


Figure 5-9 presents one example of physiological measurements used with this system. Additionally, in Figure 5-10 it is presented three different values for Pulse measurements, from which through Matlab the system identified the possible emotion state of the person. In the first plot the person was nervous, and the values were higher, from 72-76 BPM. In the second plot, the person was indiffer-



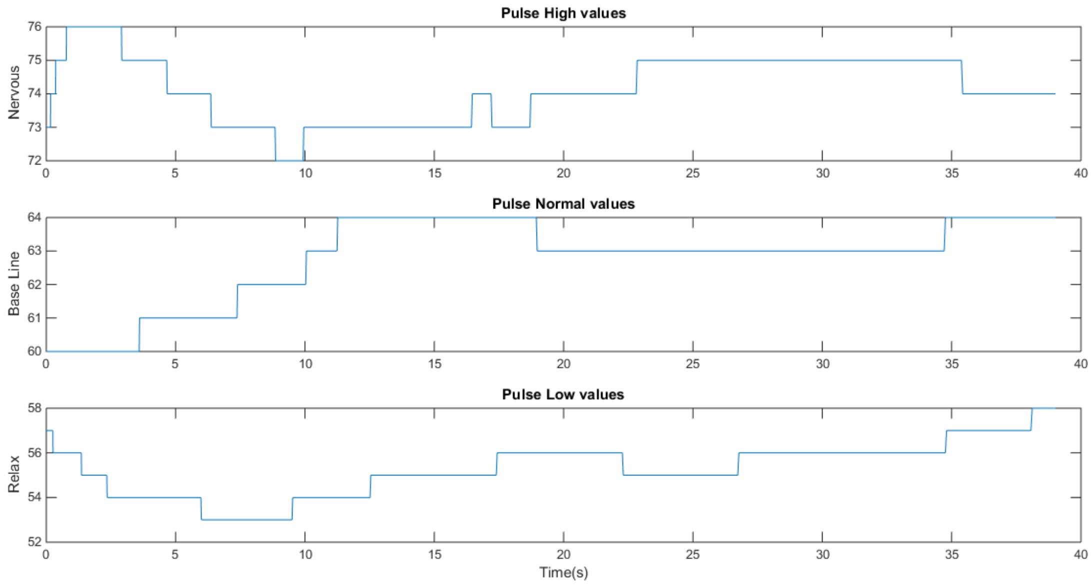
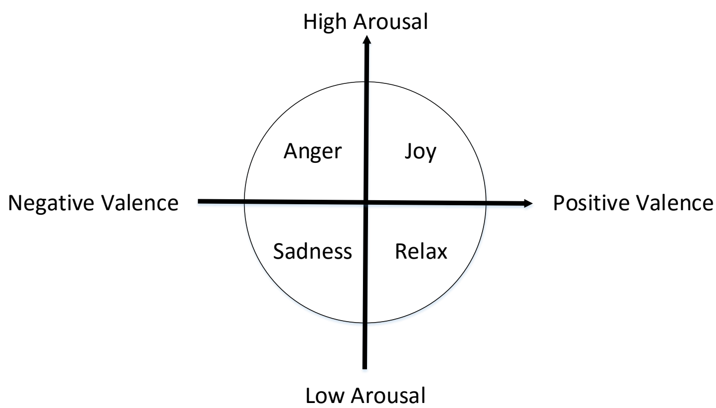


Figure 5-10: Pulse different measurements

ent, and that resulted on BPM values from 60-64 BPM. In the third plot, the person was relaxed, and for that reason, the values from Pulse were between 51-58 BPM.

5.2.2.1. Experiment 2 – Training Machine Learning

Although physiological measurements can be differentiated empirically, it was important for this dissertation if it was possible to automatically identify emotional states with physiological measurements. In order to that, it was performed this experiment which intended to know if it was possible to create a model in order to identify emotions based on physiological measurements.



To do this experiment, it was important to define what emotional stimulus that was going to use in order to train the models. If it is possible to distinguish emotional states, it is possible to identify them with physiological changes. For that reason it was used Figure 5-11 in order to make emotional stimulus over one person in order to identify characteristics of each physiological signal. The figure shows that those emotions are different and can be differentiated, and for this reason, they will be used in these experiment. These emotions are not going to be identified by valance and arousal because the used sensors cannot give that information. Instead, they will be differentiated by features of the physiological signals.

This experiment will simulate the data acquisition that each user could make in order to have an intelligent system, capable of deduct one user's emotional state based on their physiological measurements. The objective will be making constant measurements, in different periods, for different emotional stimulus.

5.2.2.1.1. Method

5.2.2.1.1.1. Material

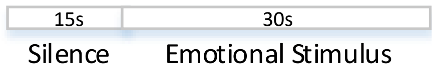
This experiment was made by using 3 different sensors that were capable of acquiring the following physiological measurements: Airflow, Body temperature, Oxygen in blood and HR. Before making this experiment, it was chosen 8 different music, two music for each emotion represented on Figure 5-11.

5.2.2.1.1.2. Participants

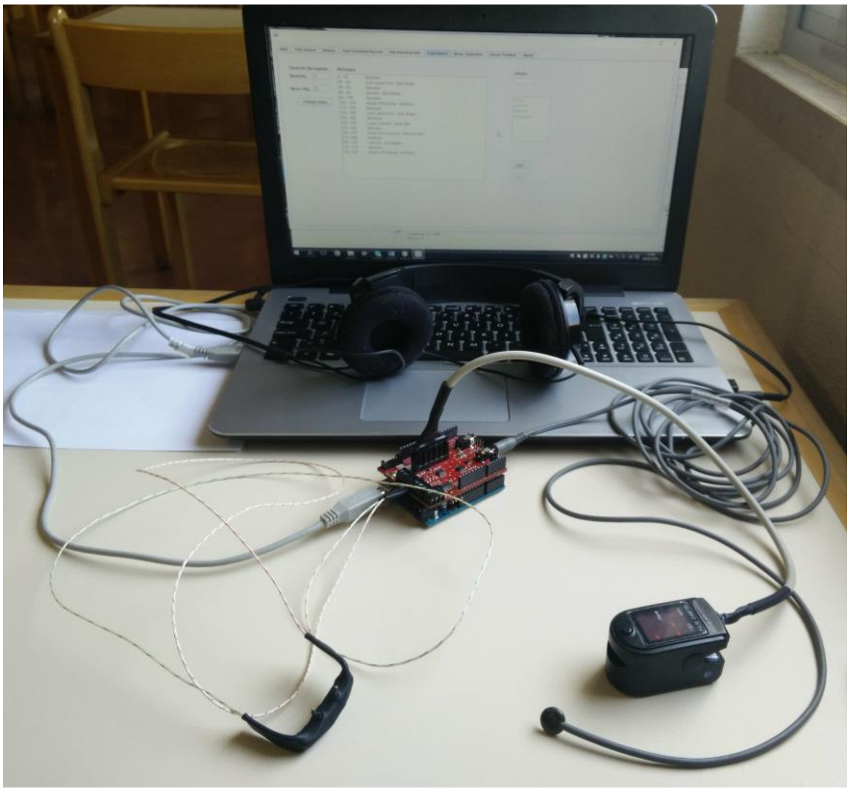
This experiment intended to be one simulation of the usage of the developed system, which required, for the same person, many data measurements. For that reason it was only tested for one person this experiment. The subject was male, right handed aged 25 years, from Faculty of Sciences and Technology, Nova University of Lisbon (FCT/UNL).

5.2.2.1.1.3. Apparatus

All music were previously saved in one music file, which already was defined the baseline time and music play time, 15 and 30 seconds, respectively. This



values were chosen based on [20] which also used 30 second clips music in order to estimate the emotional probability in a music emotion model. On this research they also used one classifier in order to predict one emotion, based on previously acquired data.



All information regarding music and user were saved on the system. This experiment had a total time of physiological data acquisition of 6 minutes. Since some music have introduction time and it don't have the same impact on the user, all music clips started from 1 min at the beginning of music.

Figure 5-12 was one example from how the apparatus was for this experiment. It is possible to identify three different sensors, in order to acquire the physiological measurements. It also has headphones because this experiment could be made in a public area. On the computer, it is possible to identify a list of music, computed by the developed program, which has all music used to make this experiment and their playing times.

5.2.2.1.1.4. Procedure

The music was played on same computer of developed system program. First it was observed if all sensors had correct signals and if the temperature sensor had stable values. Then it was defined all music that the subject would be listening to during the experiment. Finally, it was performed the experiment 2 through system tool 'Experiment'. This system tool has the characteristic of showing the correspondent time of each music that it should be playing and their playing order. This system also asks the user what is his initial/final emotion while he was listening to each music. All this information was stored on system's ontology.

During 14 consecutive days, this experiment was made for 8 different music with 4 different physiological measurements, giving a total of 448 different signals which all were saved on separated files and organized in the system's ontology. To compare this amount of signals it was used the system's tool "characteristics" which it computed and saved into separate files all defined features from each physiological signal, according to the final emotion the user had while he was listening to each music. This algorithm was made on Matlab and exported into Java code.

To build one classifier that could use features from physiological signals to identify one emotion it was used Matlab toolbox "Classification Learner". This tool trains models to classify data with different classification types, including decision trees, SVM and nearest neighbour classifiers. First, it is necessary to identify the input data (predictors) and data responses, which are represented as matrixes or tables. Then it is necessary to choose validation scheme in order to exam the prediction accuracy of the models. It can be used "cross validation" (this option is usually chosen when there are few elements to train the models), "holdout" (it is defined a percentage of data to be used for training the models and the remaining data is for testing the integrity of the model) and "no validation" (it is used all data for training the model and the same data for testing, which gives unrealistic errors). Finally, it is chosen the best classifier through their overall accuracy, confusion matrix (this option compares predicted classes per true classes) and plots of all analysed features. After chosen the best perdition model it can be exported to Matlab code in order to use it to predict new data or train the developed model.

5.2.2.1.1.5. Results

This experiment was made in order to know if it was possible to build models for each user, regarding their physiological signals, to identify their current emotional state. This process was not automatic because it is necessary to train each classifier, select the one which has better results, according to percentage of success and opposite emotions the classifier failed to predict and also this process takes too much time and processing in memory.

5.2.2.1.1.5.1. Relevant features for emotion deduction – from 14 days

It was analysed the most relevant features for emotion deduction, regarding the experiment made. For this analysis it was used all data from 14 days with Matlab tool "boxplot". This tool allows the visualization of selected information and their distribution. It has a "central box" where it is represented 50 % of the data, one central line which indicates the median of the data, two vertical lines that indicate minimum and maximum values and outliers ('+') data that represent data which is distant from other data [71]. It is important to take into account that the following results are not generic, are regarding one test subject during 14 consecutive days.

- Number of Breaths

On Figure 5-14 it is possible to observe that Relaxing is the emotion which has lowest numbers of breaths and it changes from 4 to 7 number of breaths while listening to 30 seconds of relaxing music.

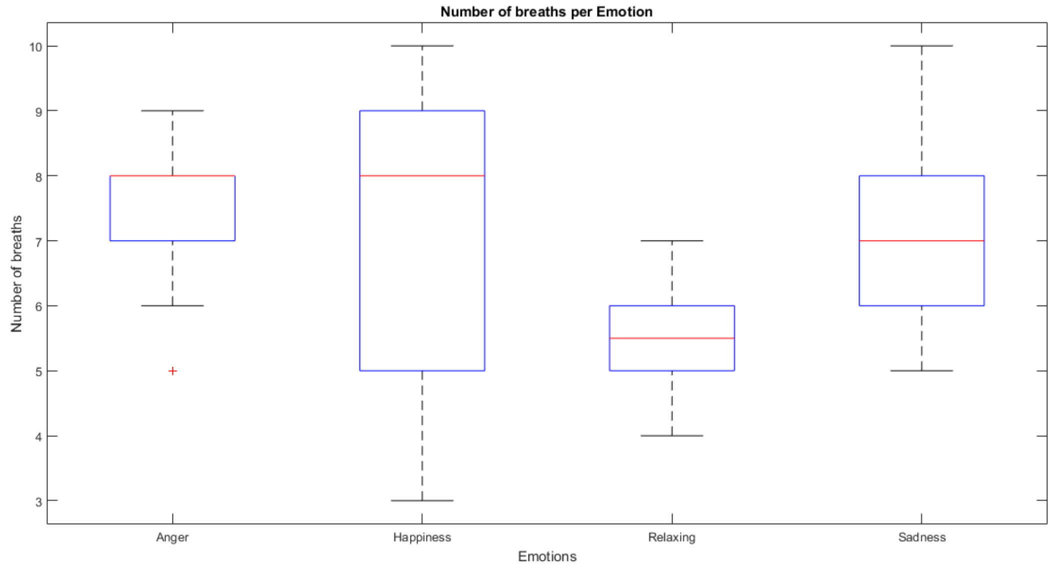
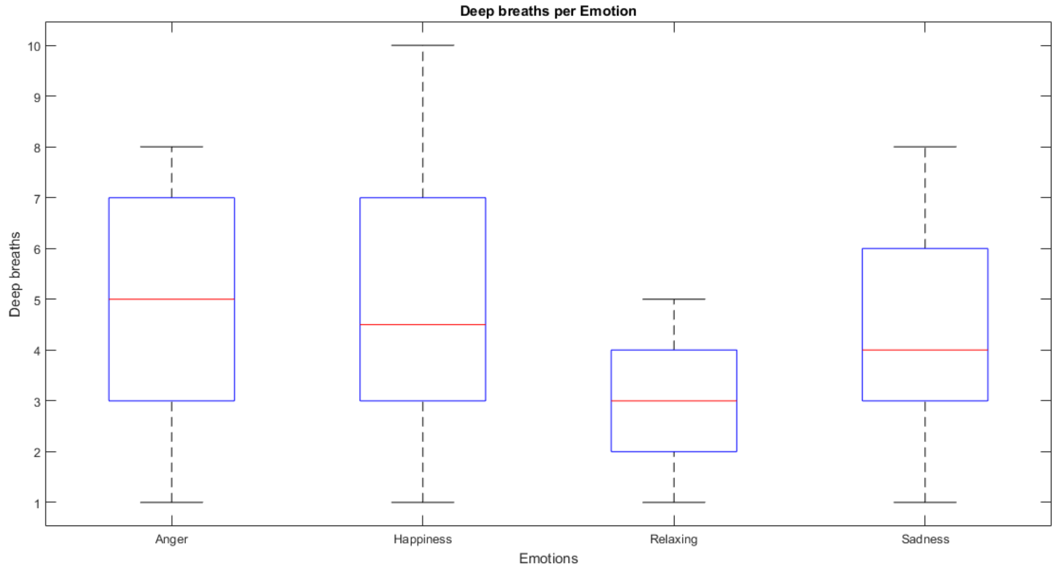


Figure 5-14: Number of breaths per emotion. This plot represents the emotions anger, happiness, relaxing and sadness with their number of breaths

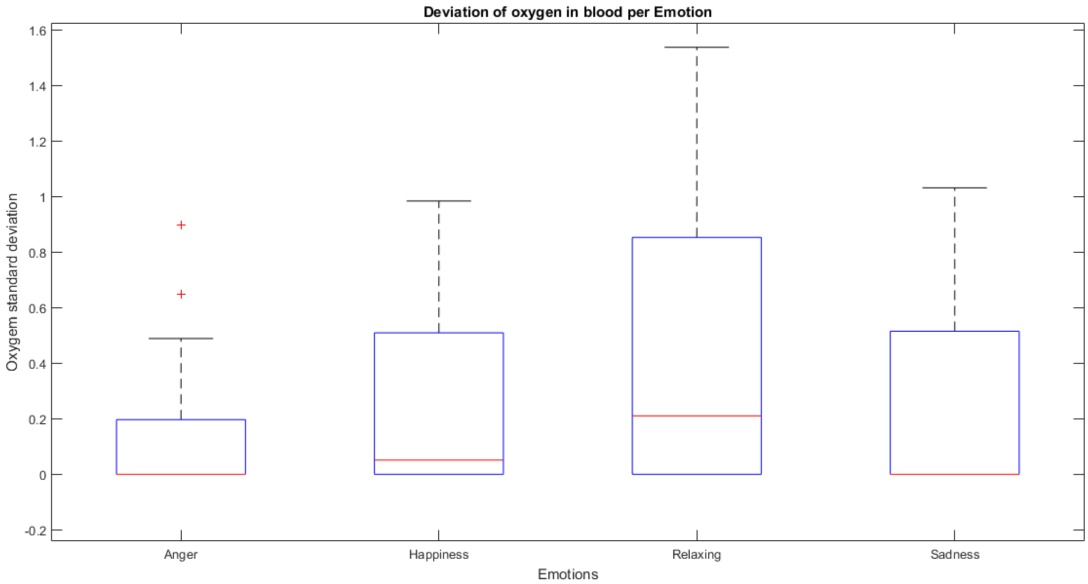
- Deep Breaths

On Figure 5-15 it is possible to differentiate Relaxing from the other emotions because it is the emotion which has the lowest number of deep breaths intervals, comparing with the other emotions.



- Deviation of Oxygen in Blood

On Figure 5-16 it is possible to differentiate Relaxing to be the emotion that has the higher variations of oxygen percentage in blood. This fact means that this subject's oxygen percentage has higher variations with emotion "Relaxing" while comparing to the other emotions while listening to the correspondent emotional music.



- Normalized Deviation of Body Temperature

On Figure 5-18, sadness is the emotion that has the lowest normalized deviation of body temperature between the emotions which were analysed. This fact means that this subject's body temperature has small variations with emotion "Sadness" while comparing to the other emotions.

- Relevant features for emotion deduction – 4 emotions

Figure 5-17 is one example of 4 different features that were extracted from 4 different sensors. On this day, it is possible to identify, empirically, that different emotions have different values on each feature.

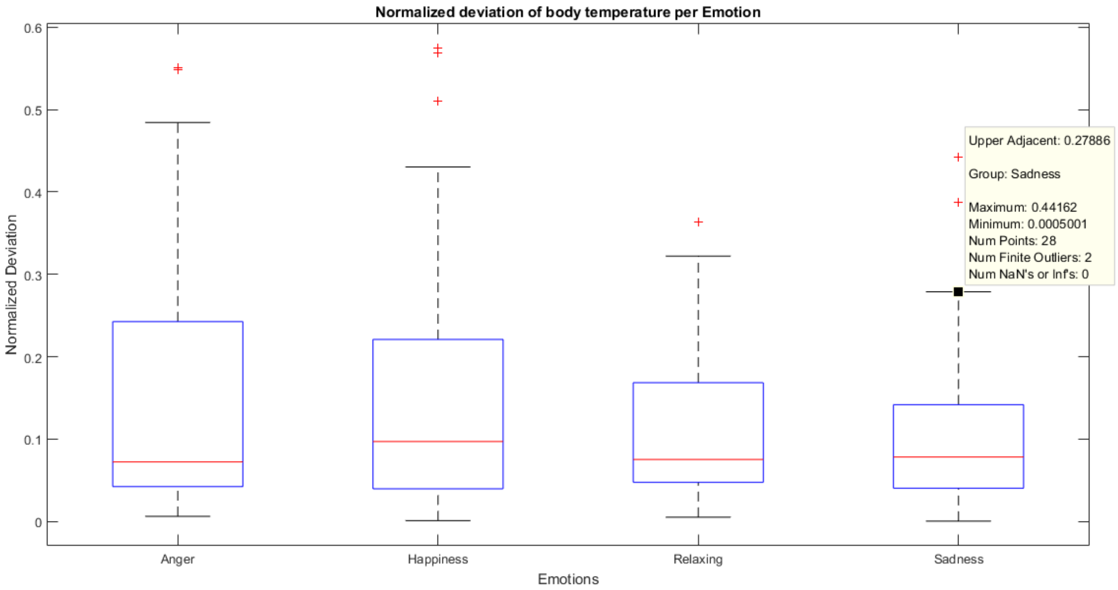
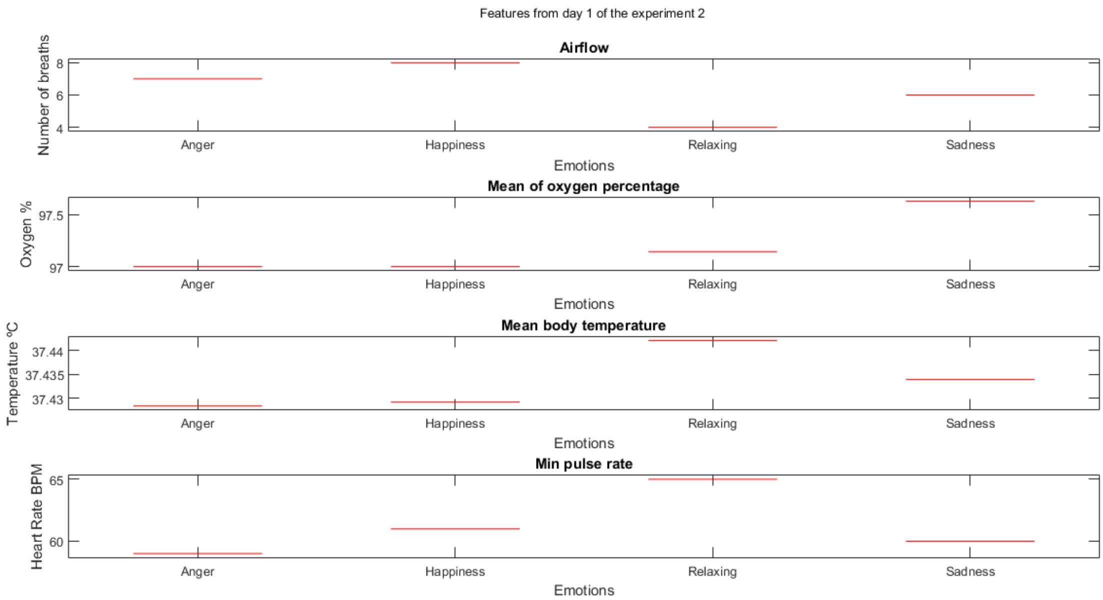
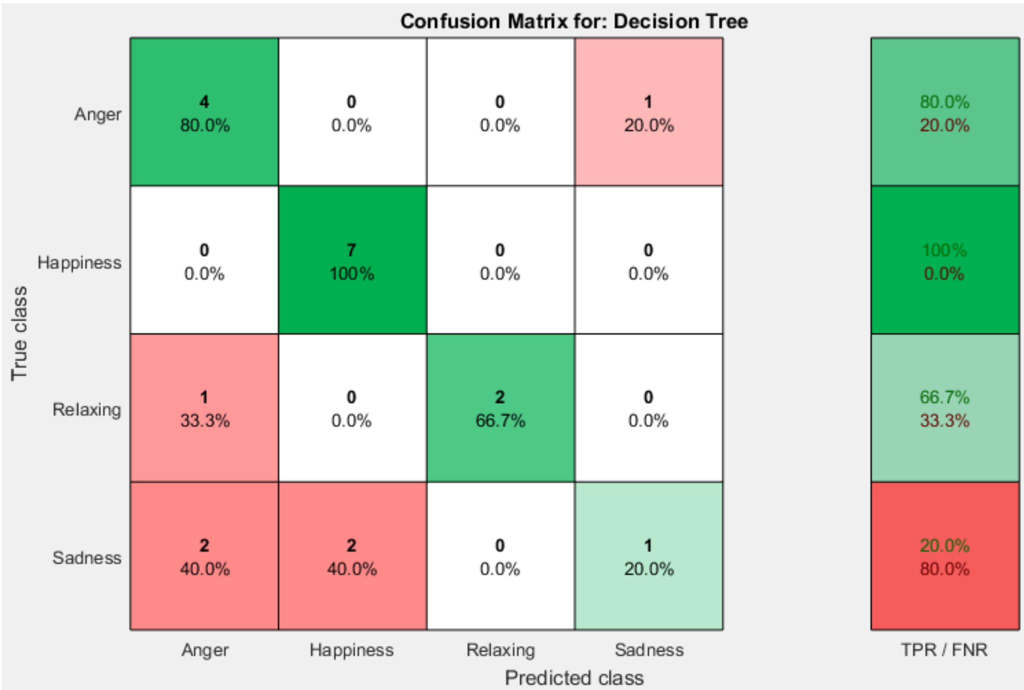


Figure 5-18: Normalized deviation of body temperature. This plot represents the emotions anger, happiness, relaxing and sadness with their variations of body temperature



5.2.2.1.1.5.2. Classifier using extracted features

For training the models it was used validation method "holdout", with 20% of data for testing (20 different emotions) and 80% for training (92 different emotions). It is important to notice that every time it was imported data for building one classifier, the results from them were always different because the data for testing is randomly chosen by Matlab. The best results for this experiment were an overall accuracy of 70.0% using 9 of 27 signal features. The confusion matrix, represented on Figure 5-19, compares true emotions per predicted emotions.



Analysing Table 5-3, it can conclude that mean of oxygen in blood is good for identify high arousal emotions. Body temperature also affects deduction on high arousal/high valence emotions. Although the features of normalized mean of HR increased the detection of Sadness emotion, for Happiness and Sadness it influenced negatively the success rate. The features: PulseAll6 – normalized means of first difference of HR was used but results were the same. This feature, along with others from other sensors, can be useful to help to deduct emotional states since it distinguished signals from negative to positive valence.

Table 5-3: Important features for deducting emotional states for one user

Features	Number of predicted emotions (Anger – Hapiness – Relaxing - Sadness)	Overall success without specific feature %(best 70)
AirAll1 – Count Respirations	1 – 2 – 0 - 0	15
OxyAll1 – Oxygen in blood: mean	3 – 5 – 2 - 1	55
OxyAll5 – Oxygen in blood: normalized deviation	2 – 4 – 2 - 1	45
TempAll6 – Body temperature: normalized means of first difference	3 – 6 – 2 - 1	60
TempAll8 – Body temperature: max value	4 – 6 – 2 - 1	65
PulseAll2 – HR: deviation	3 – 4 – 2 - 1	50
PulseAll3 – HR: means of the first difference	4 – 7 – 0 - 1	60
PulseAll4 – HR: normalized mean	2 – 3 – 2 - 2	40

5.2.2.1.1.6. Summary

With this model, for one subject and using SPO2, Respiration and Body temperature sensors it was possible to identify 91.67% (11/12) correct high arousal emotions. With this success rate, it is possible, for this subject, to build one model, represented by Figure 5-20, in order to predict subject's emotional state through their physiological signals.

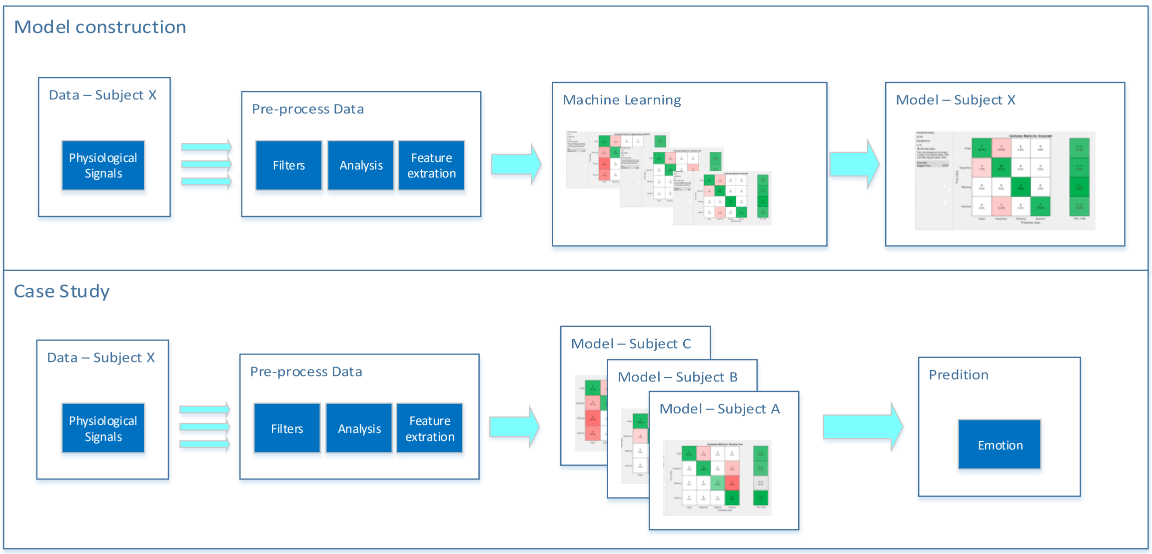


Figure 5-20: Using predicted model for developed system

The ontology reasoning has the capability to determine which music is most appropriate for listening, according to user's emotion.

5.2.3. Scenario 3

A possible third scenario could be based on all the registered users in the system, which may use a statistical probability of all these users patterns information in the database to make recommendations. Thus, when the user wants to feel comfortable, the system uses personal information (e.g. age, address and genre), from which can identify the user profile related to geographic or gender tendencies but also taking in consideration the music's characteristics (e.g. BPM, rhythm, tonality). On [79] researches also used this features from user's profile to suggest the most appropriate music for each user.

The schematic for this scenario is represented on Figure 5-5 with path number 2. The most appropriate music is chosen, not only from his/her physiological measurements and their information, but also from all information from all users. If it is known a characteristic which affects the emotional state of the user, that feature can be search in order to find the most appropriate music to the user to listen. Since there are many physiological features and it was not made any relation between features and emotions, it is going to make an example of how this scenario could bring new knowledge for this system.

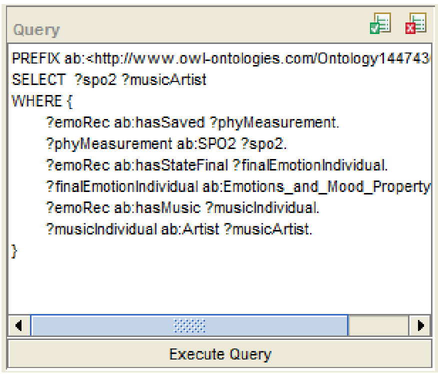
5.2.3.1. Musical stimulus over test subjects

To have realistic data, it was performed physiological tests to different persons in order to understand their physiological reaction from different music. The physiological data was collected from 10 healthy subjects (8 males and 2 females from age [23-27]) during music listening. They had minimal formal musical education and could be considered as non-musicians. All participants were explained how the several non-invasive recordings would be used during music listening and their attachments. Before beginning the test, all participants were instructed to give a list with 8 different music, two music for each one emotion represented by Figure 5-11. All music were previously acquired by internet streaming on one computer and the physiological signals were acquired on a different computer. The music was played for 30 seconds with a silence break of 15 seconds between each music. At beginning/ending of each music all participants defined their emotional state into the system. It was used airflow, body temperature, oxygen in blood and pulse rate sensors. All sensors were tested before the experiment in order to place them in best positions to get more accurate information.

Participants were instructed to sit comfortable and relax and carefully listen to each music while their physiological signals were recorded. The participants were asked, at the beginning/ending of music about their physiological state.

5.2.3.2. Search one physiological characteristic from all users

Considering that one person wanted to be relaxed, he/she wanted to find one music which make his/her HR to have minimum value as possible. In order to do that it was necessary to search from all music that all users listened to, in order to identify that particularity. Although it is known that slow HR doesn't mean that someone is relaxed, this example was only made to see the applications this system can have.



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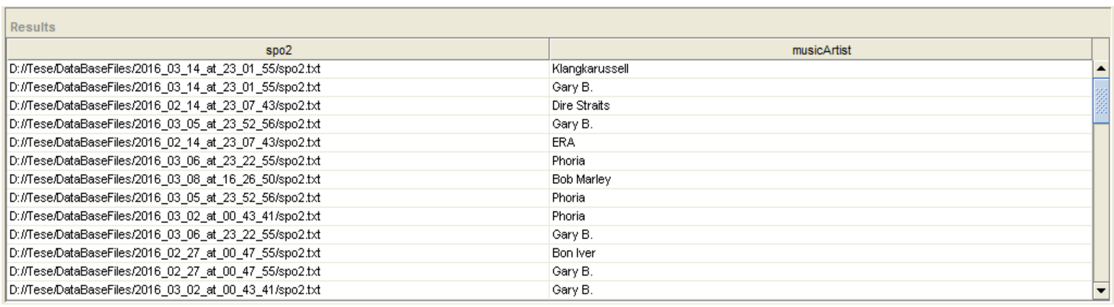

Results

spo2	musicArtist
D://Tese/DataBaseFiles/2016_03_14_at_23_01_55/spo2.txt	Klangkarussell
D://Tese/DataBaseFiles/2016_03_14_at_23_01_55/spo2.txt	Gary B.
D://Tese/DataBaseFiles/2016_02_14_at_23_07_43/spo2.txt	Dire Straits
D://Tese/DataBaseFiles/2016_03_05_at_23_52_56/spo2.txt	Gary B.
D://Tese/DataBaseFiles/2016_02_14_at_23_07_43/spo2.txt	ERA
D://Tese/DataBaseFiles/2016_03_06_at_23_22_55/spo2.txt	Phoria
D://Tese/DataBaseFiles/2016_03_08_at_16_26_50/spo2.txt	Bob Marley
D://Tese/DataBaseFiles/2016_03_05_at_23_52_56/spo2.txt	Phoria
D://Tese/DataBaseFiles/2016_03_02_at_00_43_41/spo2.txt	Phoria
D://Tese/DataBaseFiles/2016_03_06_at_23_22_55/spo2.txt	Gary B.
D://Tese/DataBaseFiles/2016_02_27_at_00_47_55/spo2.txt	Bon Iver
D://Tese/DataBaseFiles/2016_02_27_at_00_47_55/spo2.txt	Gary B.
D://Tese/DataBaseFiles/2016_03_02_at_00_43_41/spo2.txt	Gary B.

B

On Figure 5-21-A it is defined one query in order to search all physiological measurements which have the desirable feature. It has also specified the desirable emotion, which in this case, is relaxing. Figure 5-21-B represents some results from previously query. With this information it is possible to extract all features from the signals and chose the most appropriate music to the user listen to. In this example, it was analysed 80 HR signals from 10 different users. In this study case, the advantage of having a larger group of users would be specified the user's personal information according to their personal information, for instance, the same age, address and genre. This research, with this high-level features, would bring new knowledge and more accurate results than the previous one.

5.3. Validation

In respect to the hypothesis validation, the author demonstrated in chapter 5, sub-section 5.2.2.1 that by designing a knowledge-based framework which integrates devices like sensors with particular analytics algorithms to identify specific users' physiological signs patterns that it was possible to identify physiological patterns, in order to build one model capable of detecting, by these pattern and for each profile.

The developed system is capable of identifying physiological characteristics that can be used for other research works. Other researchers in the same lab where this work was conducted already used the developed application in the area of e-learning. Their work intends to identify the role of classic background music in different student's attention and performance during e-learning tasks.

As a result of this work the author of this dissertation published one paper and one report. The paper named "Profiling Based on Music and Physiological State", which was shown in conference "I-ESA2016 – Interoperability for Enterprise Systems and Applications". The report "Semantic architecture for sensors" was placed under "Inovação e Estudos de Tecnologia" and "RePEc - IDEAS" repositories. This report focus the scientific and social aspects of this dissertation, which are the impacts of sensors and music on our society.

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6

6. Conclusions

The presented research work demonstrates that human affective states are very complex, but in what regard to musical effects, interesting interactions can be achieved. This early work generated results that lead us to conclude that it is possible to change affective states based on profiling and user preferences about music.

The proposed framework establishes a person's profile with early physiological assessment and later proposes music selections for targeted affective states. That is based on learning through previously records, saved on the ontology model that will empower a selection of music that aims to improve the user's affective state. The usage of this framework, with a somehow invasive approach, it is possible to determine the best music selection, from a pool, according to a person's inferred affective state.

The proposed system can be used in other and totally different applications, as in evaluating attention in students or trainees. It could help to identify the type of music to be integrated in eLearning materials to potentiate trainees attention. Other similar applications could be applied to industry as in trying offering better working environments to workers in such a way to increase their efficiency accomplishing their tasks. However, the main purpose of this system is not to be a product to any people but a prototype to analysts/researchers to facilitate their emotional and physiological analysis, which results/conclusions would potentiate better environments or feelings to people.

6.1. Future work

Although the fact that the hypothesis of this dissertation was a success, there is much more development of this system in order to be used on other researches.

Since the system can support alternative scenarios, as mentioned above, in the future is intended to explore its integration with independent music players, like Spotify, Youtube, Itunes or Soundcloud. This possible scenario should use all the registered users in the systems, which through particular data analysis to find particular patterns over such information would make music recommendations. Thus, the system (if allowed by users) would use their personal information e.g. age, geographical region, genre and personal music's appreciation characteristics (e.g. beat per minute, rhythm, tonality) to propose a playlist using such independent players.

Thus, to make this system a possible product, in order to use it for well-being situation while the user performs their daily life, is to integrate this system in a wearable technology. There are already devices which records physiological measurements and they could be integrated with this in order to suggest the most appropriate music according to their emotional state.

7

7. Annexes

7.1. Experiment 1

The experiment 1, which was made in order to empirically conclude if the sensors changed with emotional stimulus, described on sub-section 3.2, was used with different pictures in order to induce different reactions over the test subjects. The pictures used in this experiment were:

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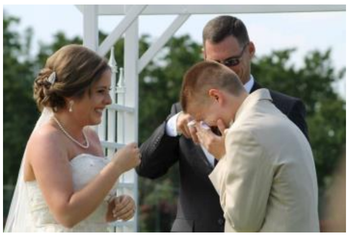

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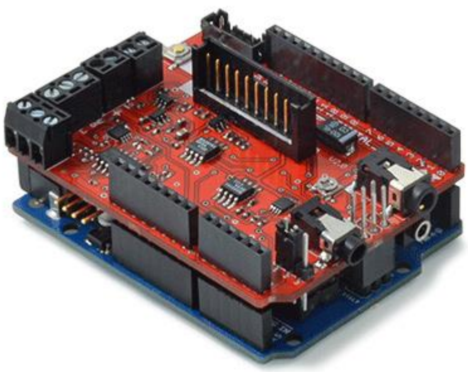
7.2. Manuals

In order to know how to use this developed system, it was created two different manuals, each one of them with different purposes. The User Guide is one manual to know how to use the program. The Low Level Guide is another manual which contains specific information of how to install and make important configurations.

7.2.1. User Guide

A Framework for Profiling based on Music and Physiological State

Manual – User Guide



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FACULDADE DE CIÊNCIAS E TECNOLOGIA UNIVERSIDADE NOVA DE LISBOA

E-Health shield Connections

On Figure 1 it is represented the shield that was used for this system. It connects one Arduino and sends the data acquired by the sensors through serial communication for the computer. The data from the sensors is send, by the e-Health shield, into the appropriate port of the Arduino.

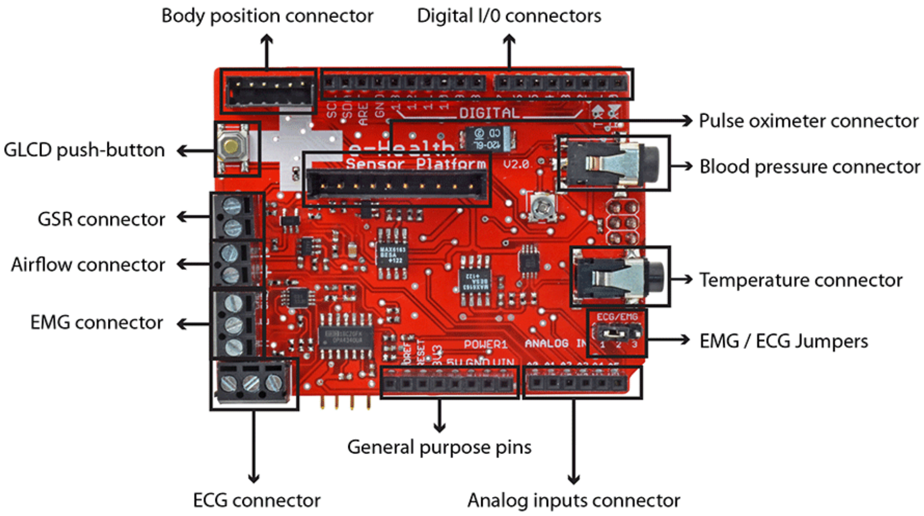


Figure 1 - E-Health shild that connects into one Arduino or Raspberry Pi

Important Concepts

Emotion Record

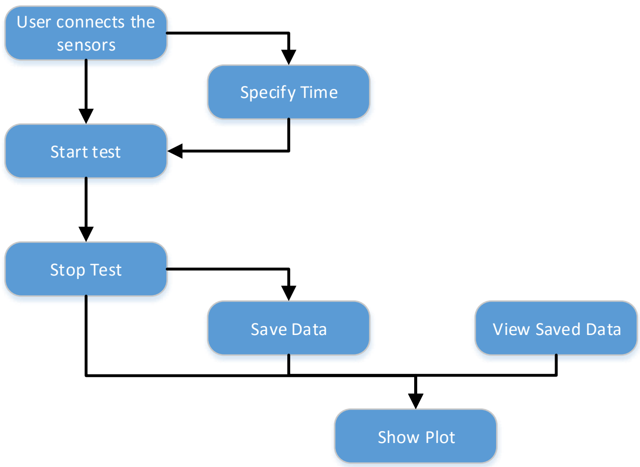
To perform an analysis for music listening, it was relevant for this program to save the initial and final emotion the user is feeling while listening each music, in order to analyze, individually, what types of music that can change each emotional state.

Emotional Experiment

For this program it was important to acquire several music that induce different emotions for each user. For this reason, it was created an Emotional Experiment, which is a group of emotional records, each one of them with individual characteristics and information. It is characterized by a baseline, which represents a period of time that the user isn't being stimulated. Music play time corresponds to the period of time which the user is listening to one music.

Test sensors

This option allows the user to verify if each sensor is working properly. Since this program was made for the e-Health shield, it cannot be possible to choose ECG and EMG simultaneously.



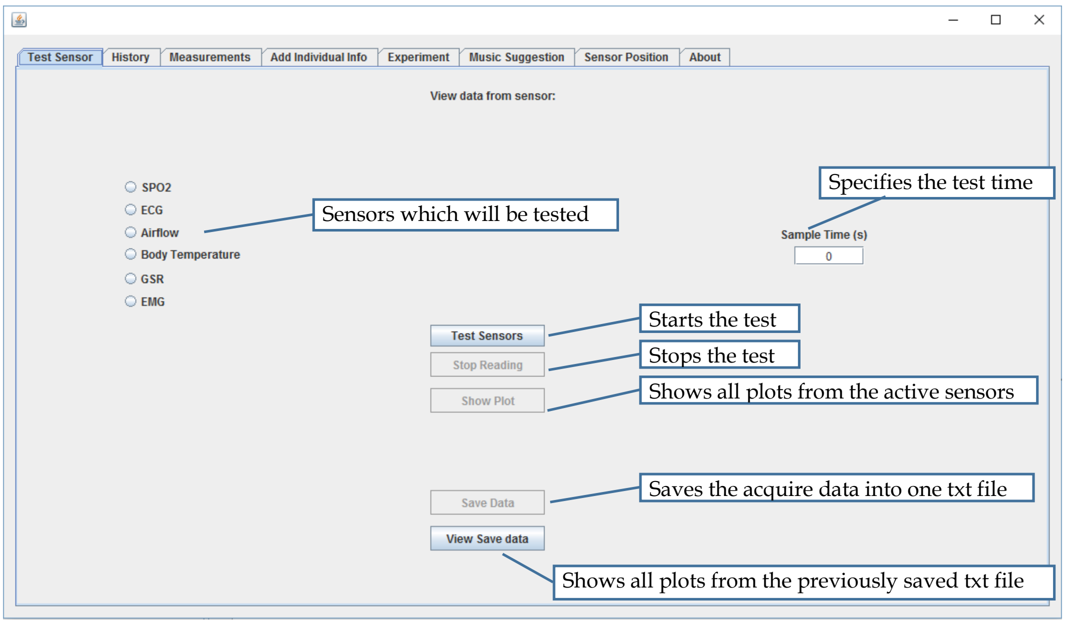
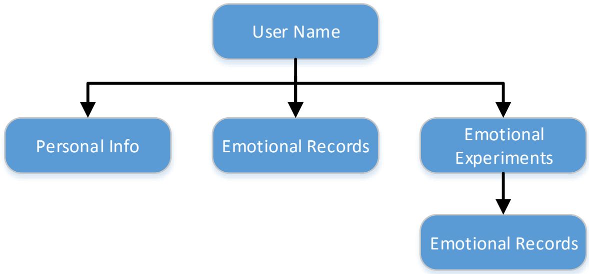


Figure 2 - Test sensors

History

This option allows the user to know personal information about all users as well as information regarding emotion records and emotion experiments. First it is necessary to choose the name of the user (represented on Figure 3) and then the program enables the other options from this tab, which are represented by Figure 4, Figure 5 and Figure 6.



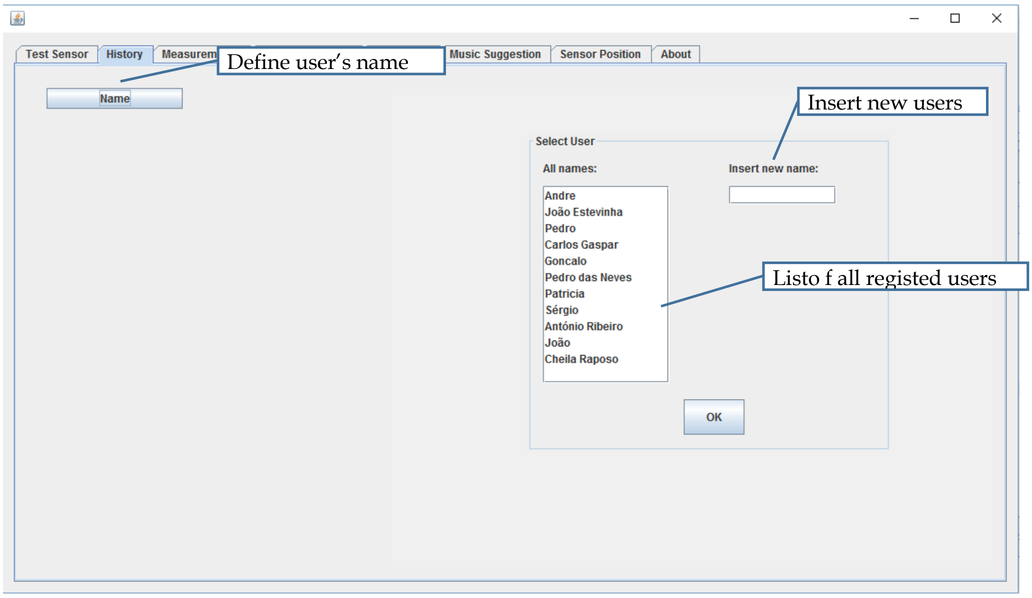


Figure 3 - Choose user name

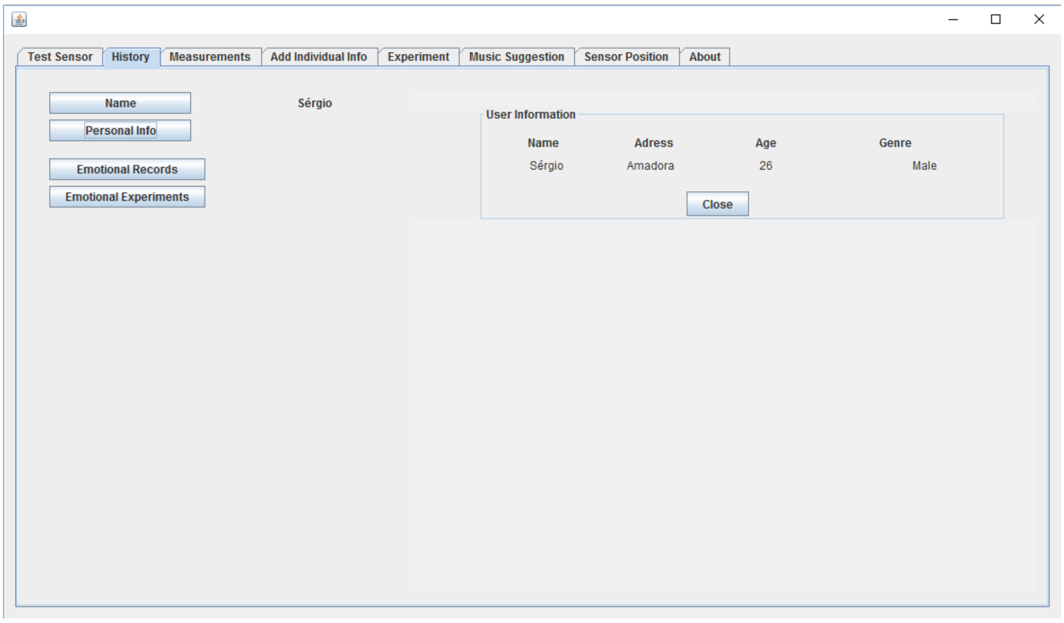


Figure 4 - Personal Information

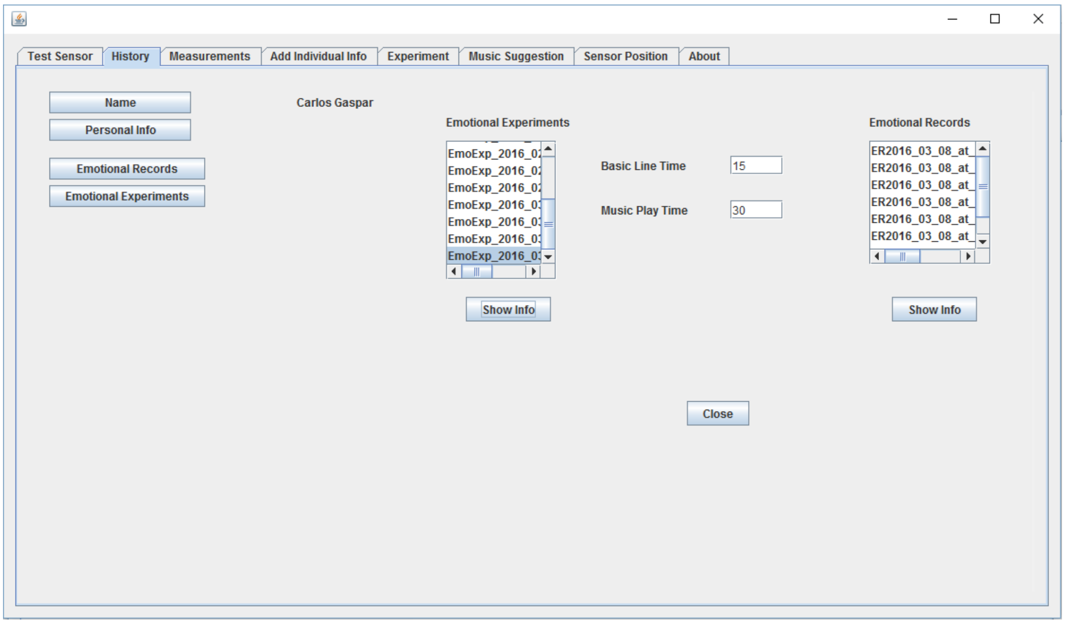


Figure 5 - List of all Emotional Experiments and their information

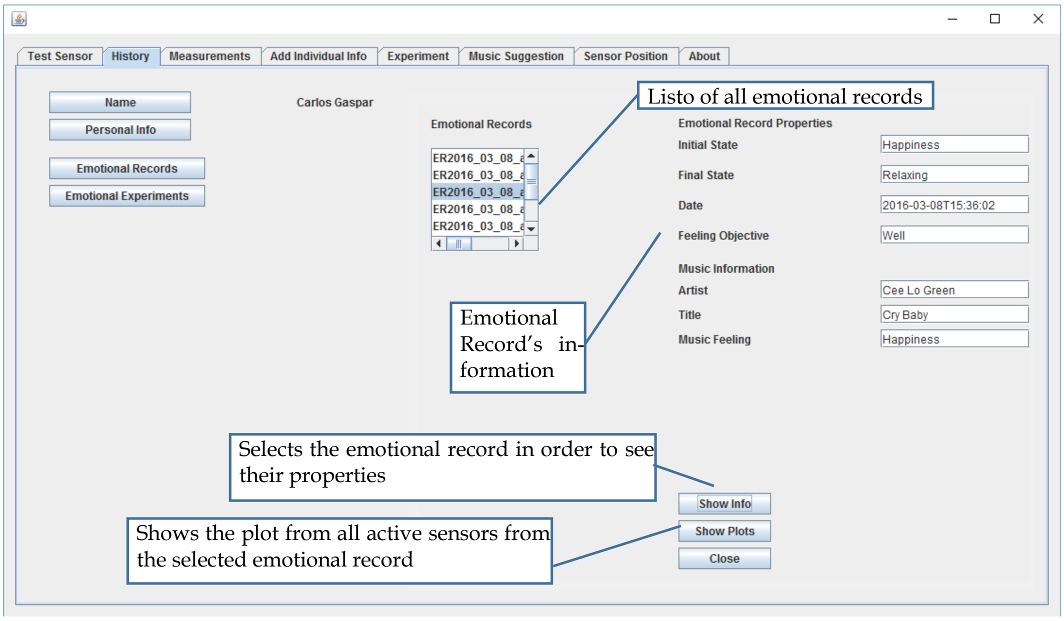
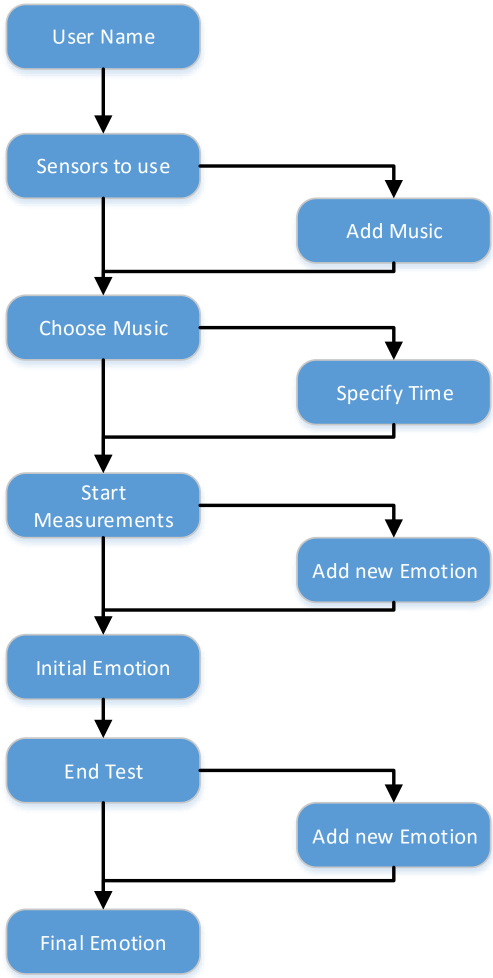


Figure 6 - Information of Emotional Records

Measurements

This system's option allow the user to save one Emotional record. This Emotional Record is associated to one user, a group of active sensors, one music and one emotion at beginning and ending of the selected music.



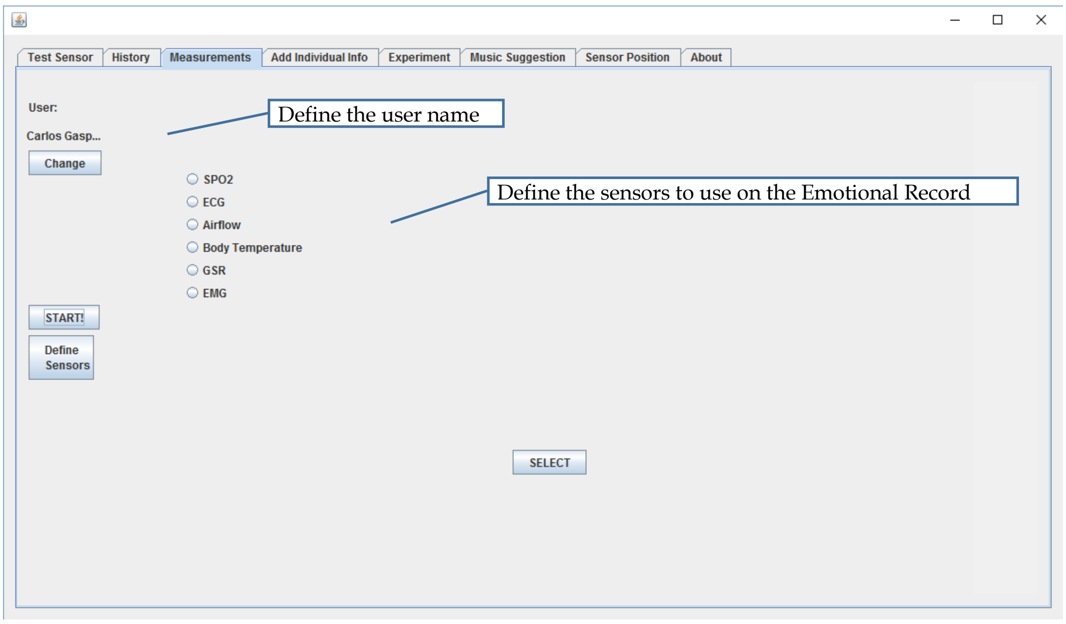


Figure 7 - Making one Emotional Record - define sensors

In measurements, the user can choose the music from their own list, which are all music that the user inserted, and for that reason it doesn't have their emotional label. The user can also choose the music from the list of the other users. This list has the emotional label that was defined when the user introduced the music.

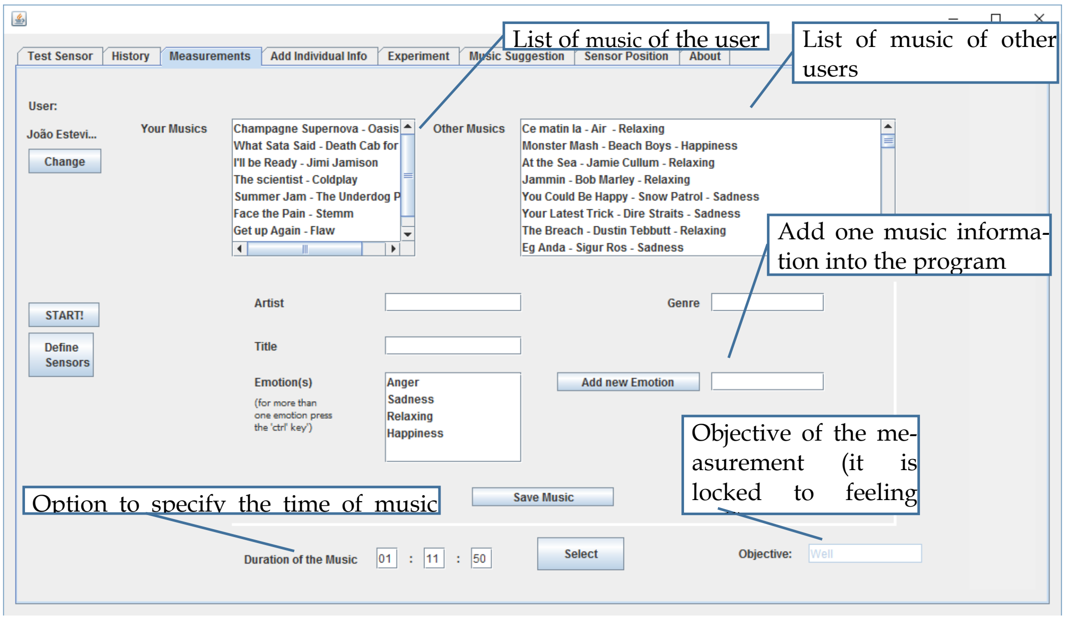


Figure 8 - Making one Emotional Record - choose musical stimulus

gure 9 is shown at the beginning and ending of the music and it intends to define the emotion felt by the user at these two different moments.

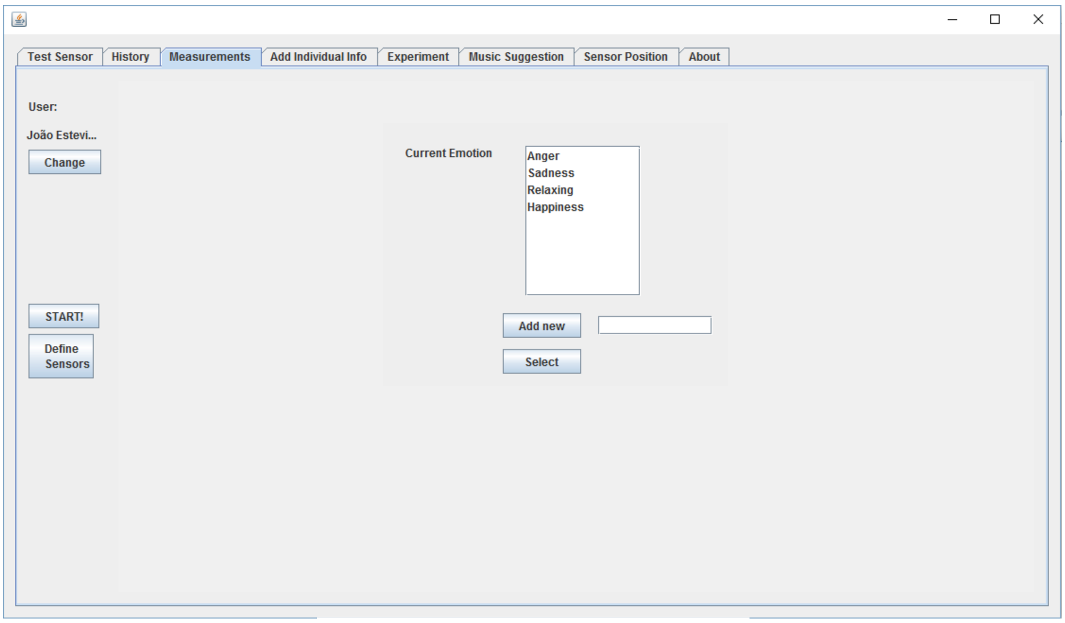


Figure 9 - Specify current emotion

During data acquisition, the program have the following appearance, illustrated on Figure 9.

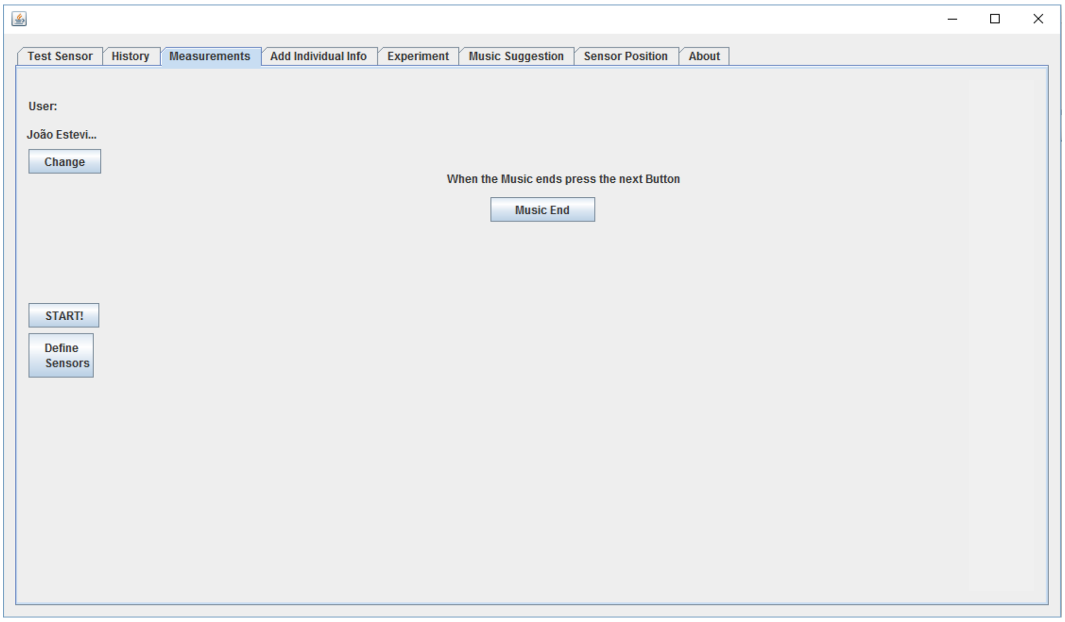


Figure 10 - Data acquisition

Add individual Information

This option allows the user to add specific information, such as new music, new user and compute the signal's characteristics.

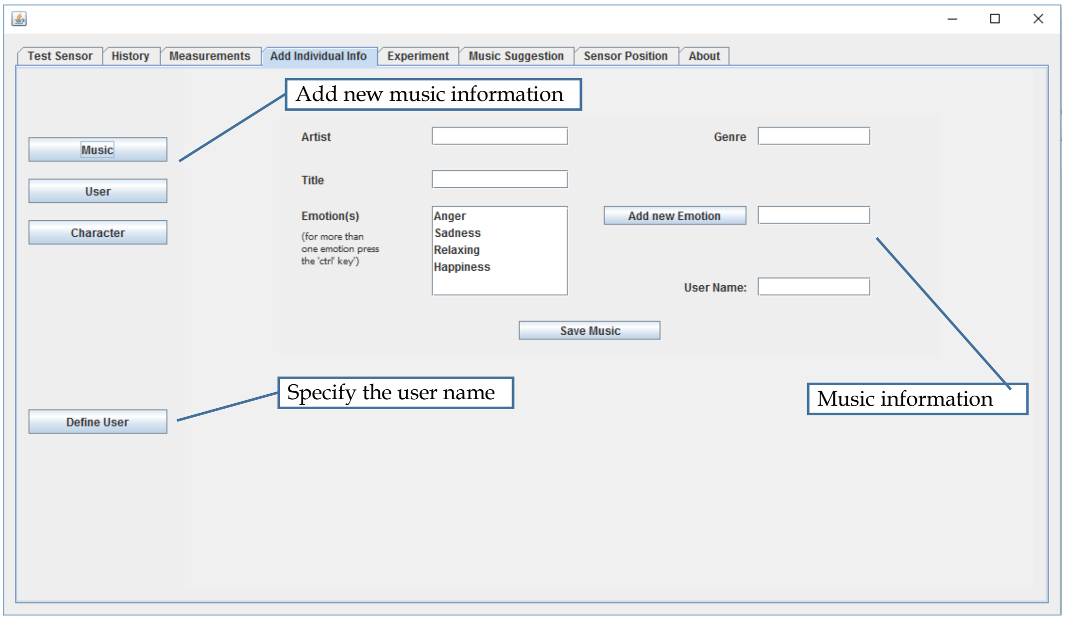


Figure 11 - Add new music Information

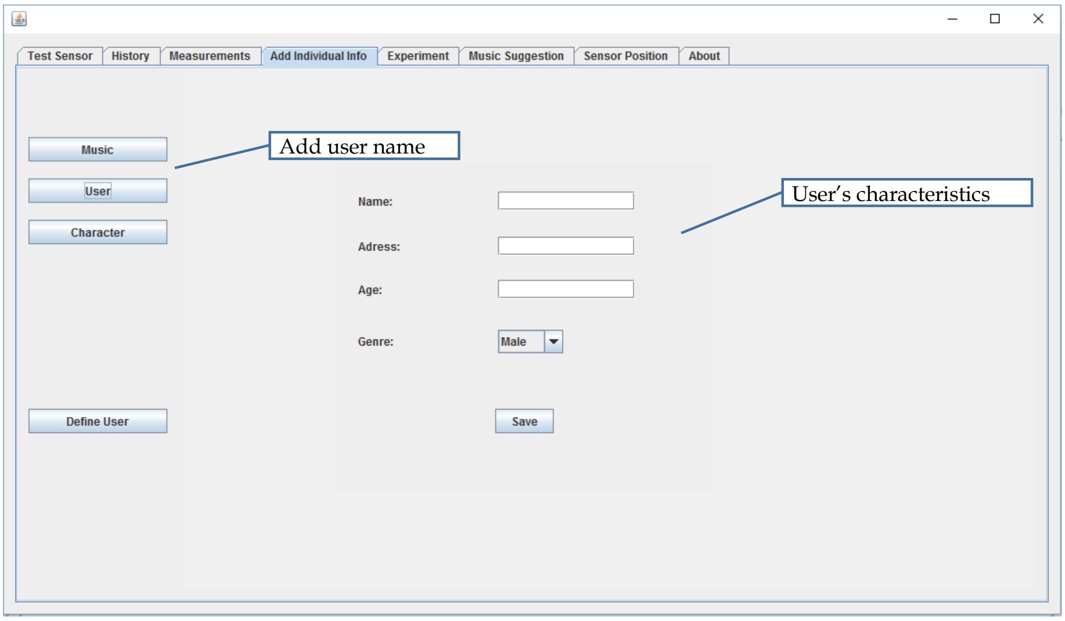
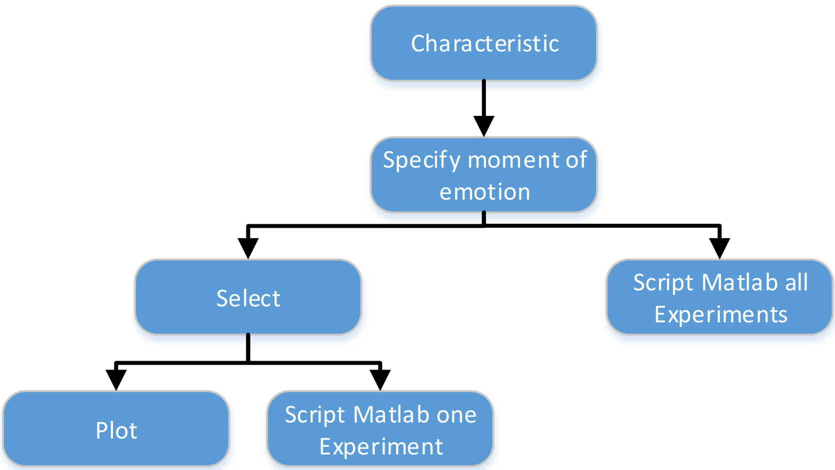


Figure 12 - Add new User Information



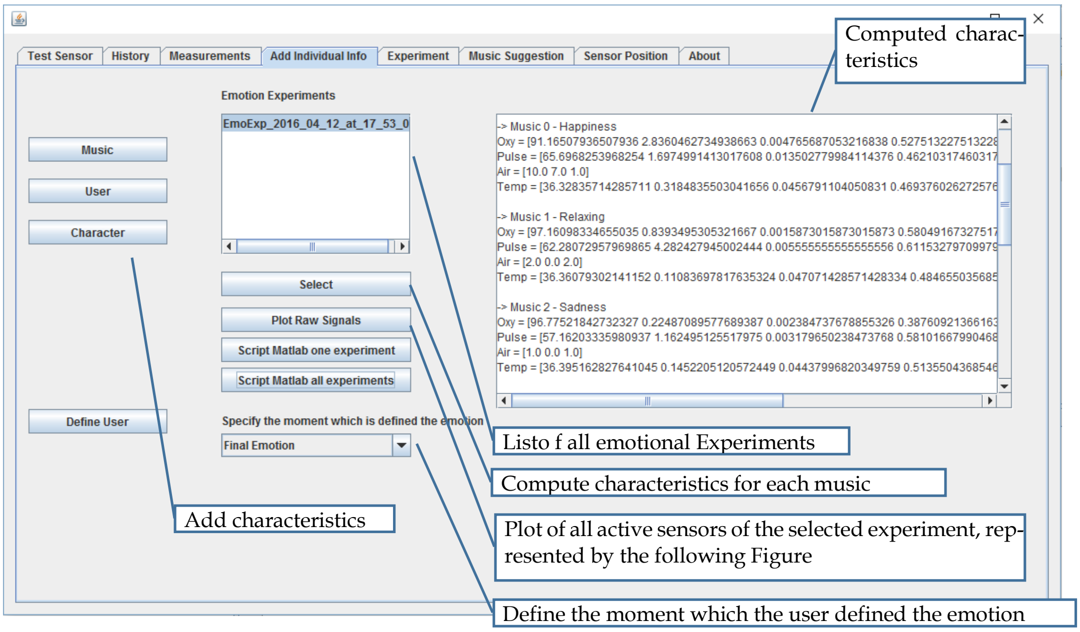


Figure 13 - Characteristics of one emotional experiment

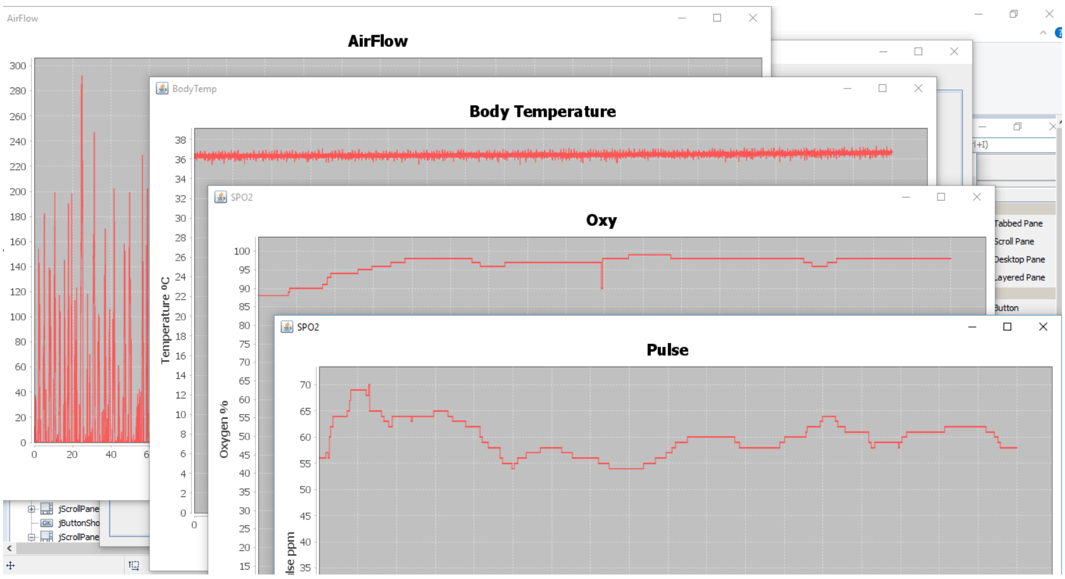


Figure 14 - Plots of one emotional experiment

For the functionality of creating the characteristics of one and all experiments, the program makes one .txt file in order to use directly with Matlab program

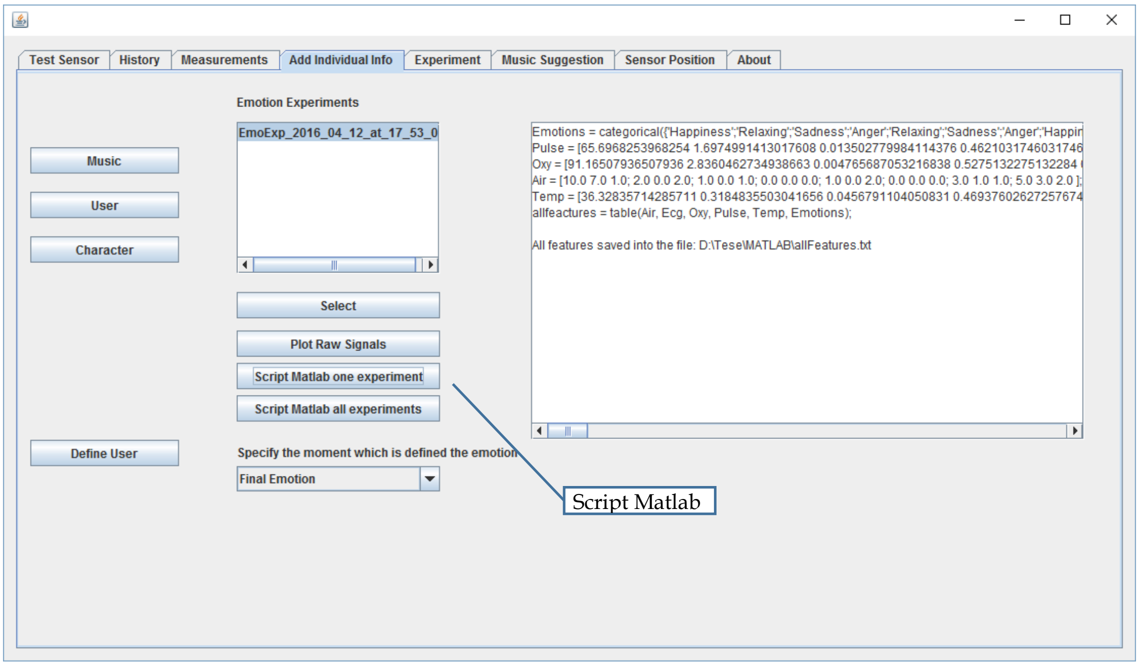


Figure 15 - Matlab Script for one emotional Experiment

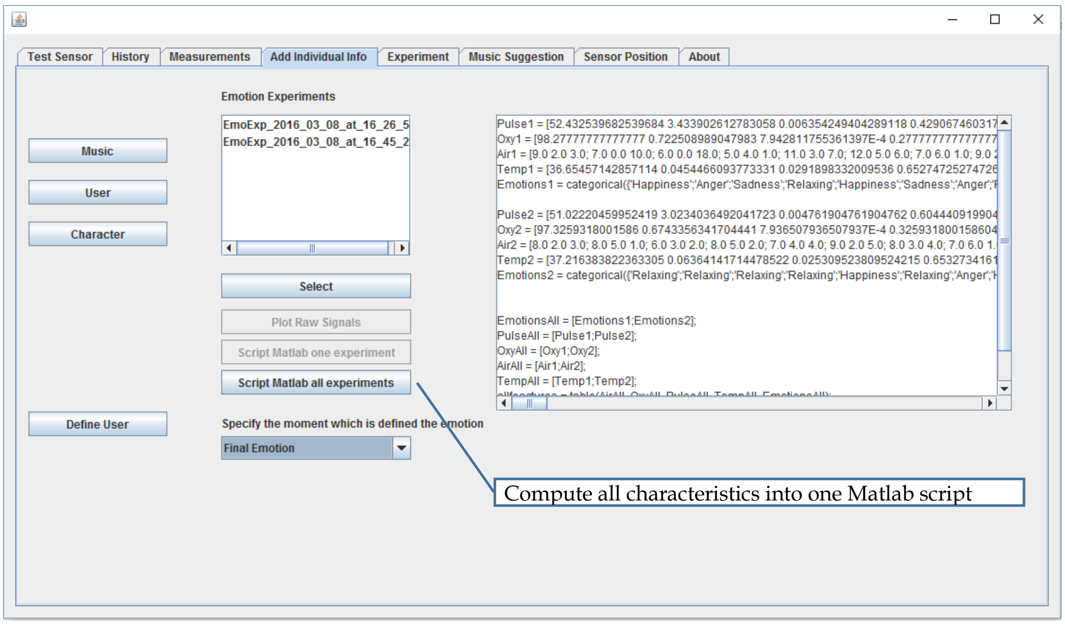
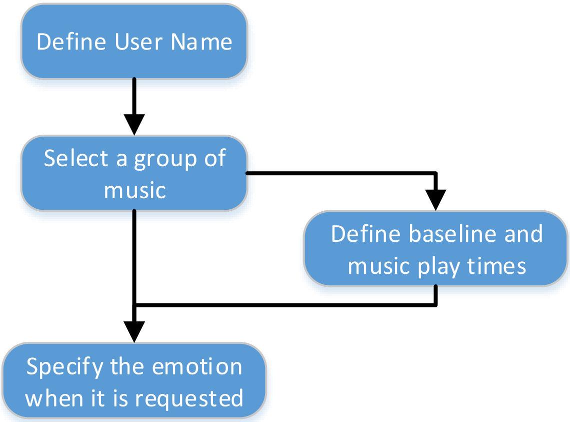


Figure 16 - Matlab script for all emotional experiments from the selected user

Make emotional Experiment

This option allows the study of how the physiological signals changes according to different musical stimulus.



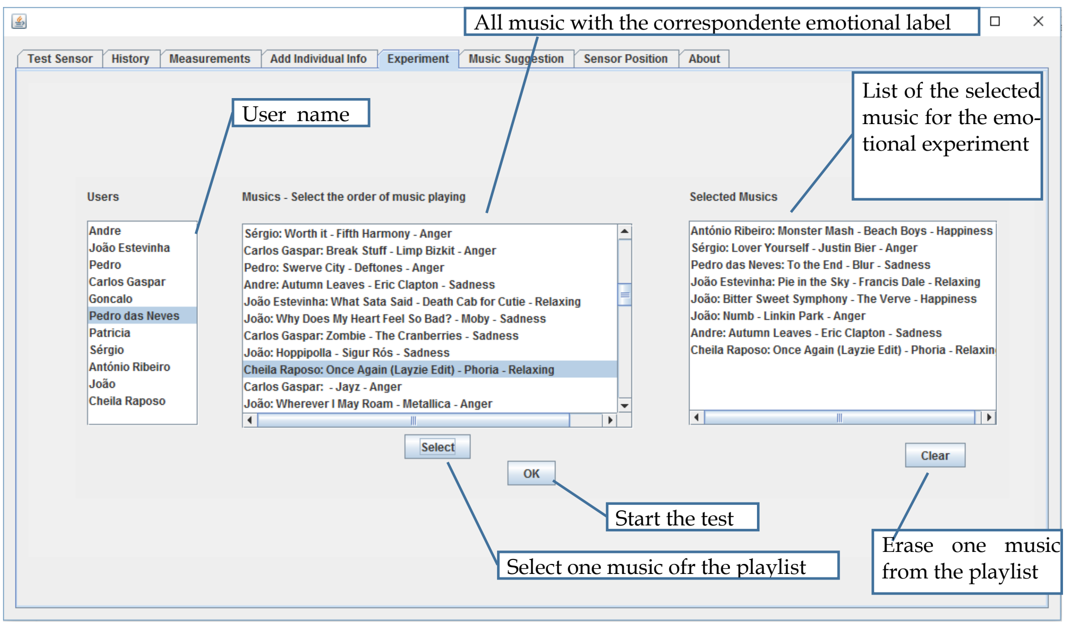


Figure 17 - Emotional Experiment – Define user name and list of music of the experiment

In Figure 18 it is possible to change the Baseline and Music play time and these values correspond, respectively, to the silence time, where the user don't listen to any music, and to the time while the user is listening to one music

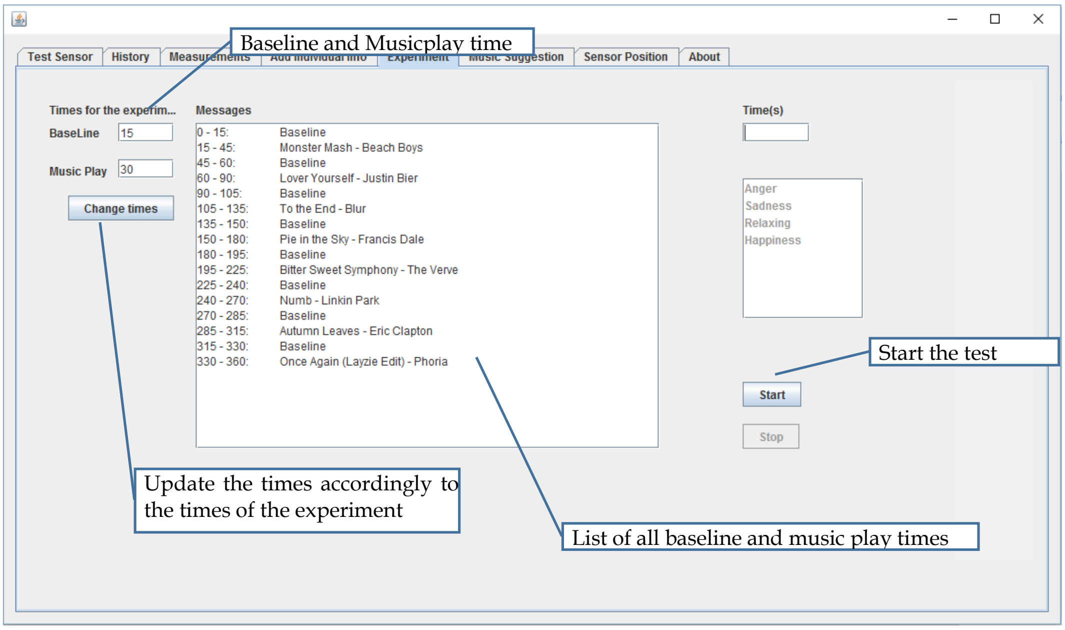


Figure 18 - Change baseline and music play times

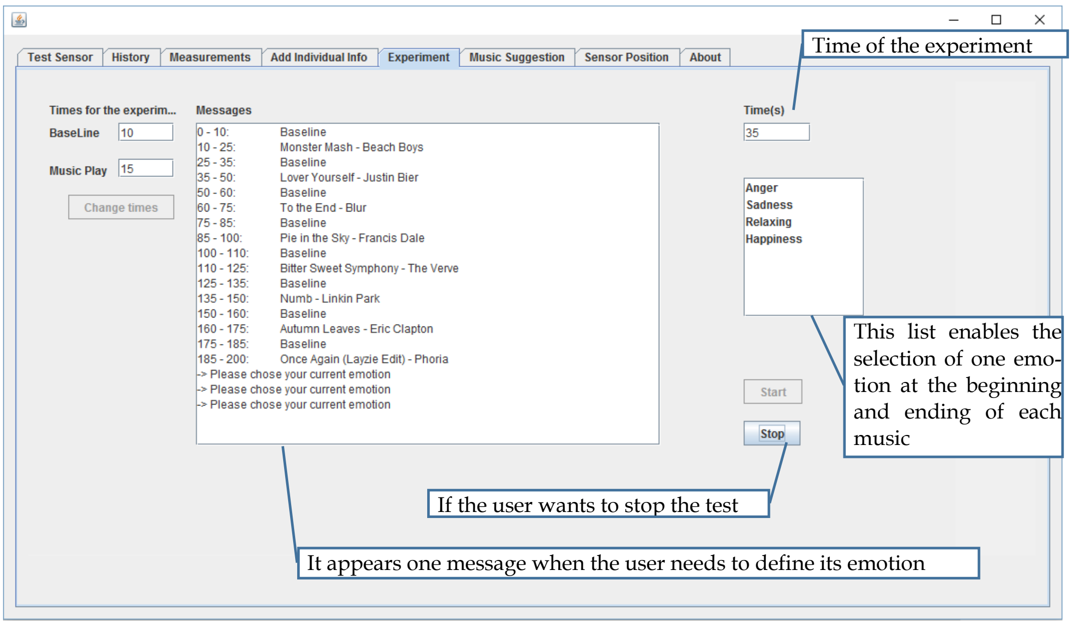


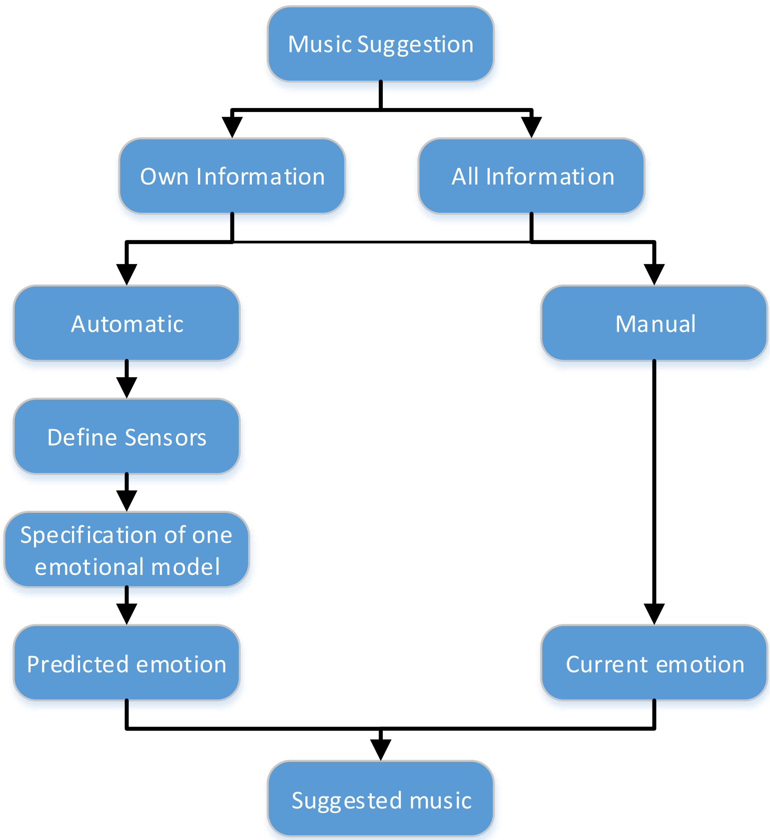
Figure 19 - During one emotional experiment

Music Suggestion

In Emotion recognition: Automatic, the system uses one model made by a machine learning in order to predict the emotion felt by the user. This prediction is made based on the user's physiological measurements. This option requires 30 seconds of physiological measurements.

In Emotion recognition: Manual, the emotional state of the user is defined by the user, which selects its emotion.

The option of using the other's information in order to suggest the music is to have the emotional reactions of the other users saved on this system.



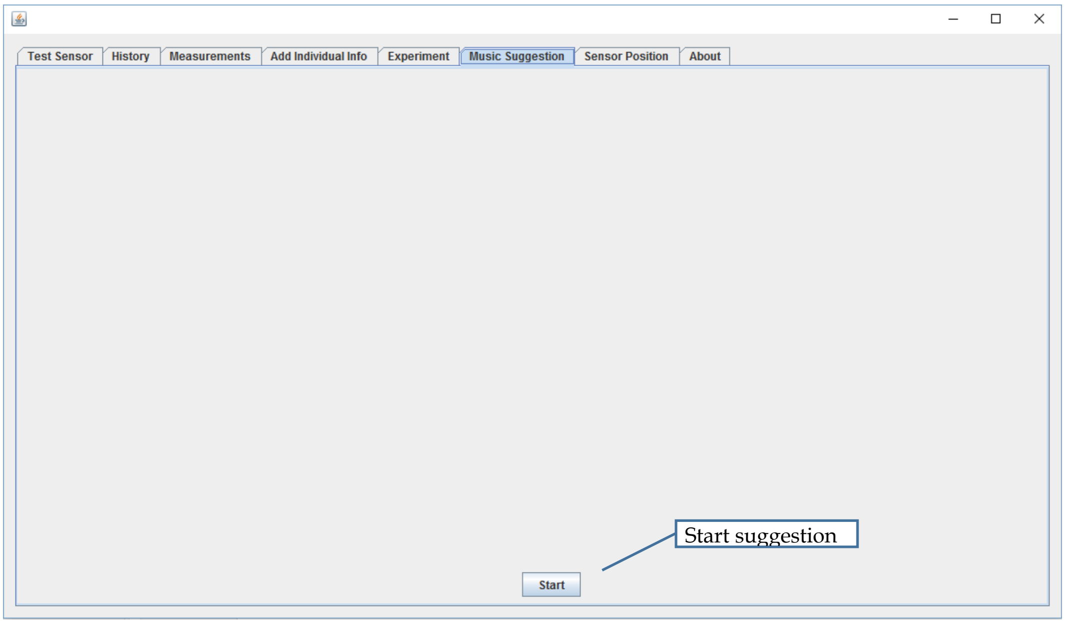


Figure 20 - Music Suggestion

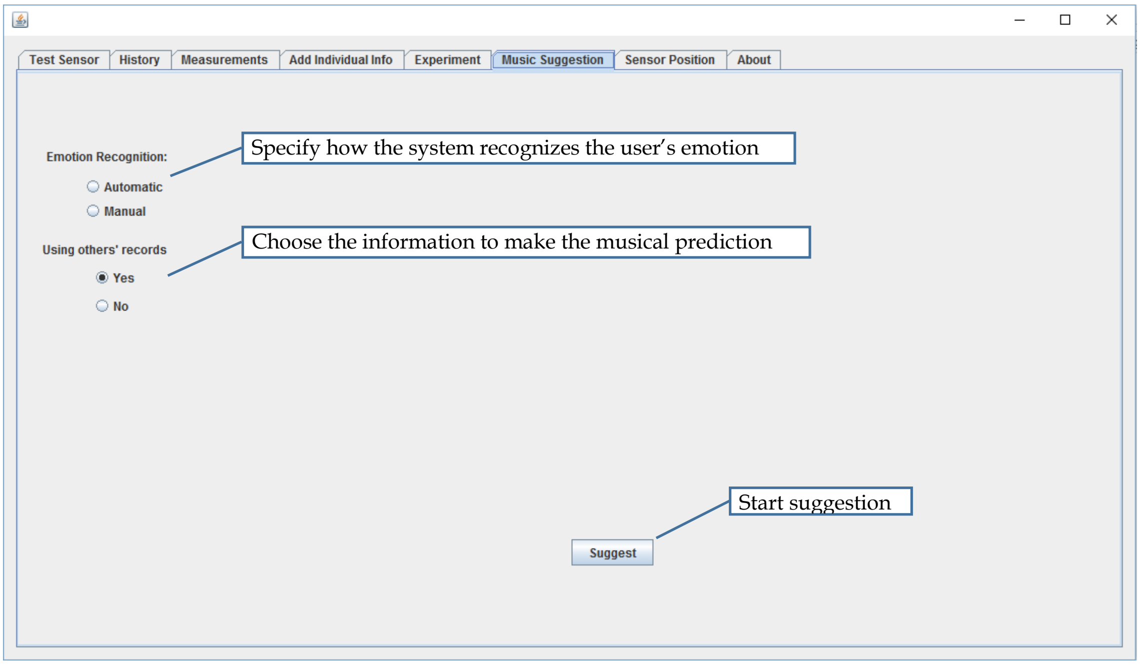


Figure 21 - Suggestion Specifications

Automatic Suggestion

In 22, it is necessary to specify the sensors that are going to use.

To use the machine learning path, it is necessary, a priory, to add the libraries into the JAVA program. This fact happens because Matlab predictions uses objects, and these objects must be already saved into the libraries.

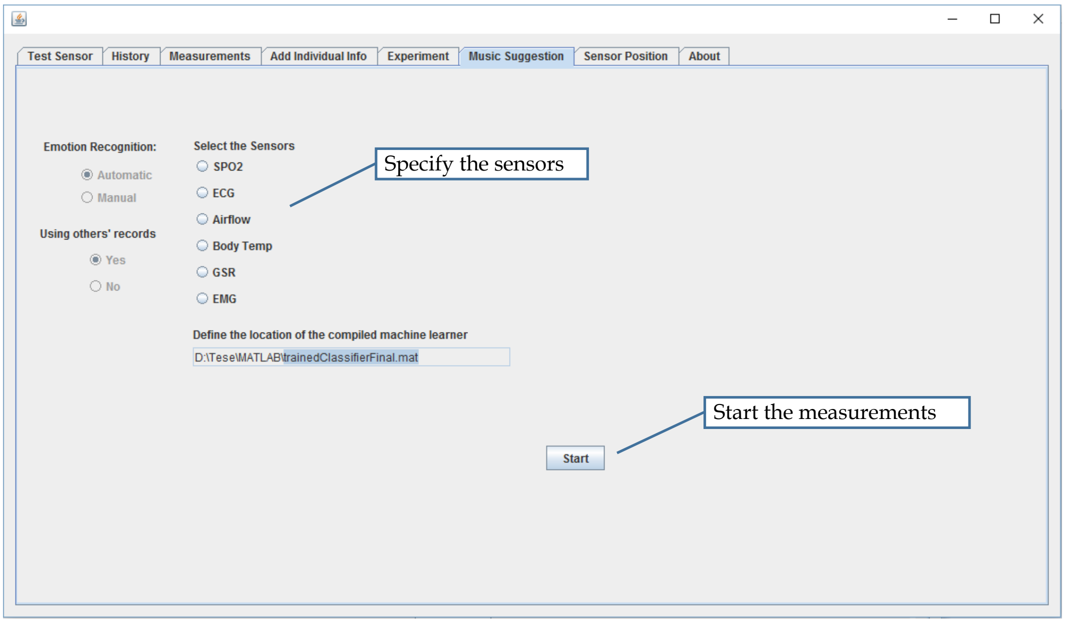


Figure 22 - Music Suggestion – Sensors and emotional model

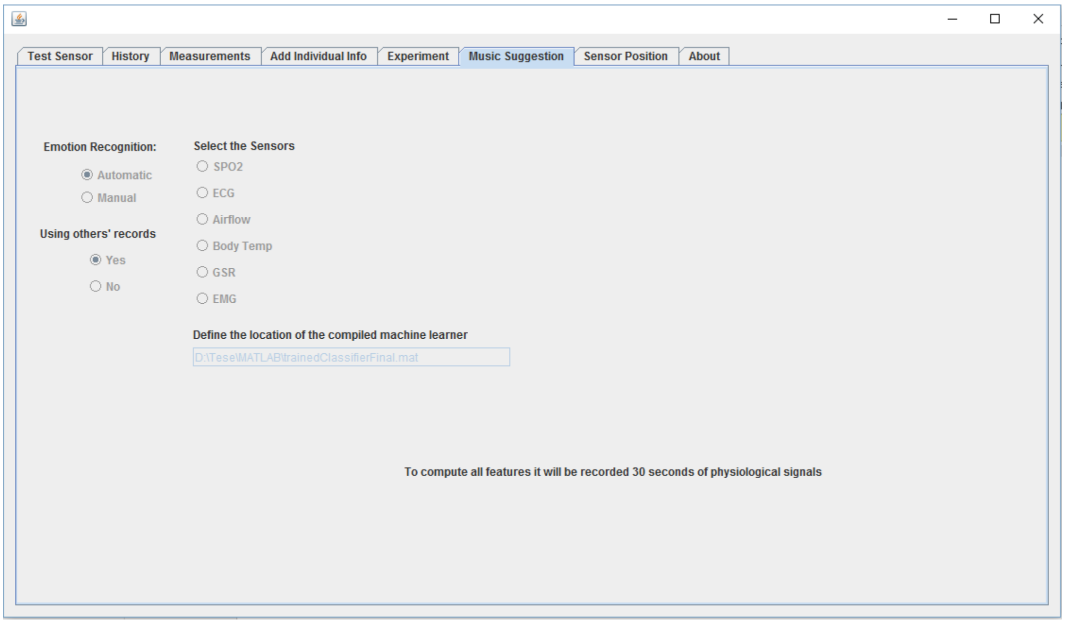


Figure 23 - Data acquisiton for music suggestion

In Figure 25 it is possible to observe that in the current emotion list, the emotion is blocked. If the user didn't agree with the predicted emotion, he can click on the 'Edit' bottom and choose the most appropriate emotion he is feeling.

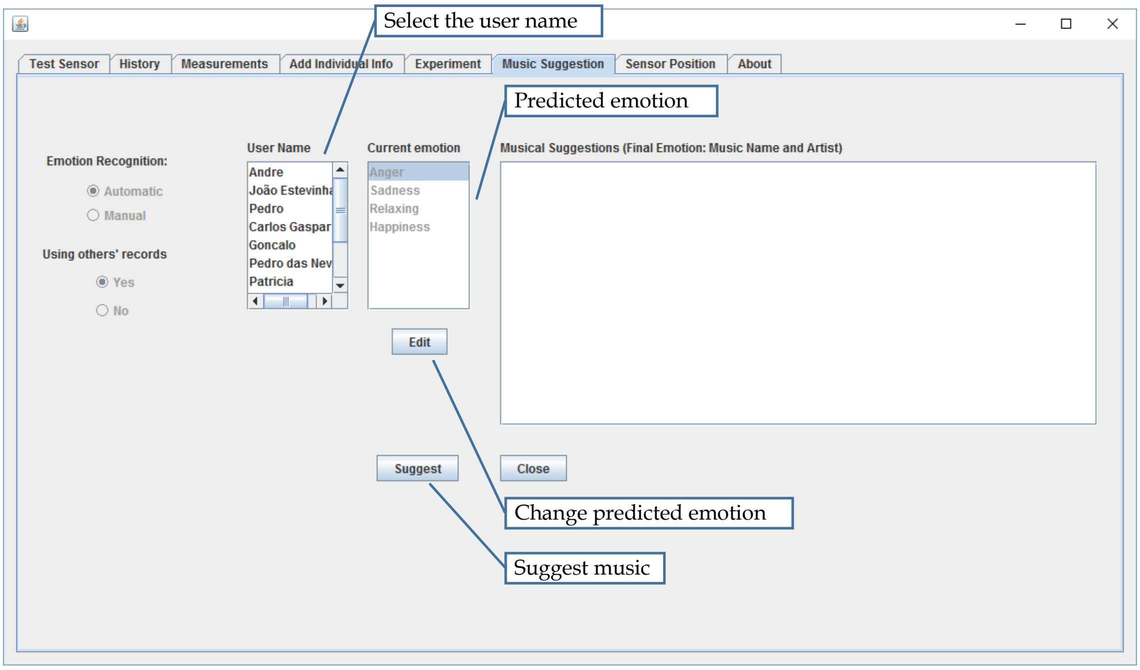


Figure 24 - Predicted emotion

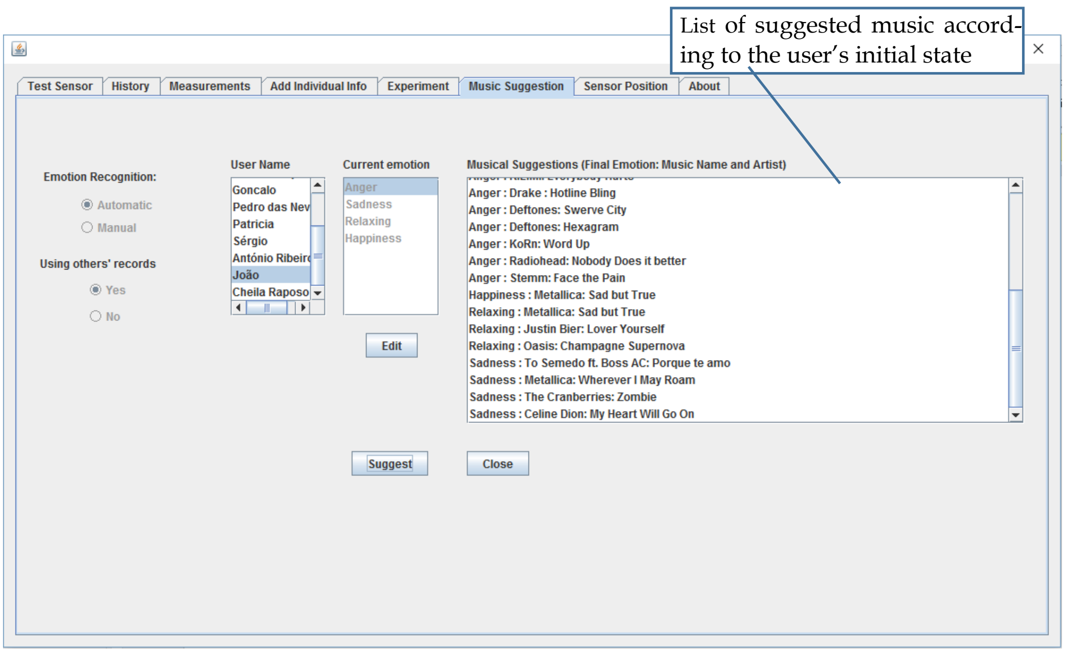


Figure 25 - Music suggestion using information of all users that used this system

Manual Suggestion

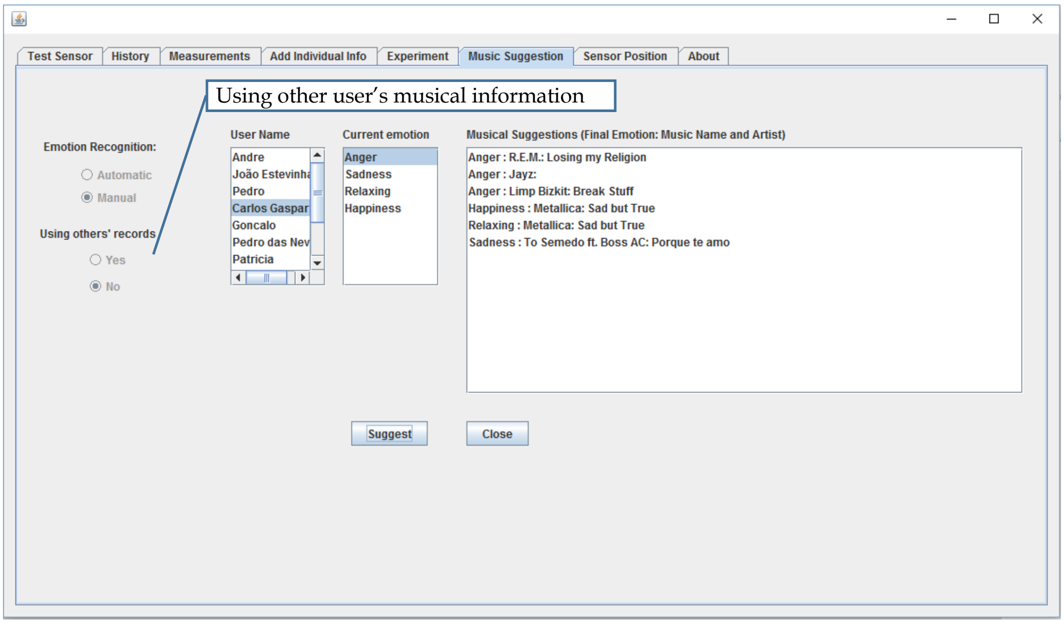


Figure 26 - Manual Suggestion - using only information of the user

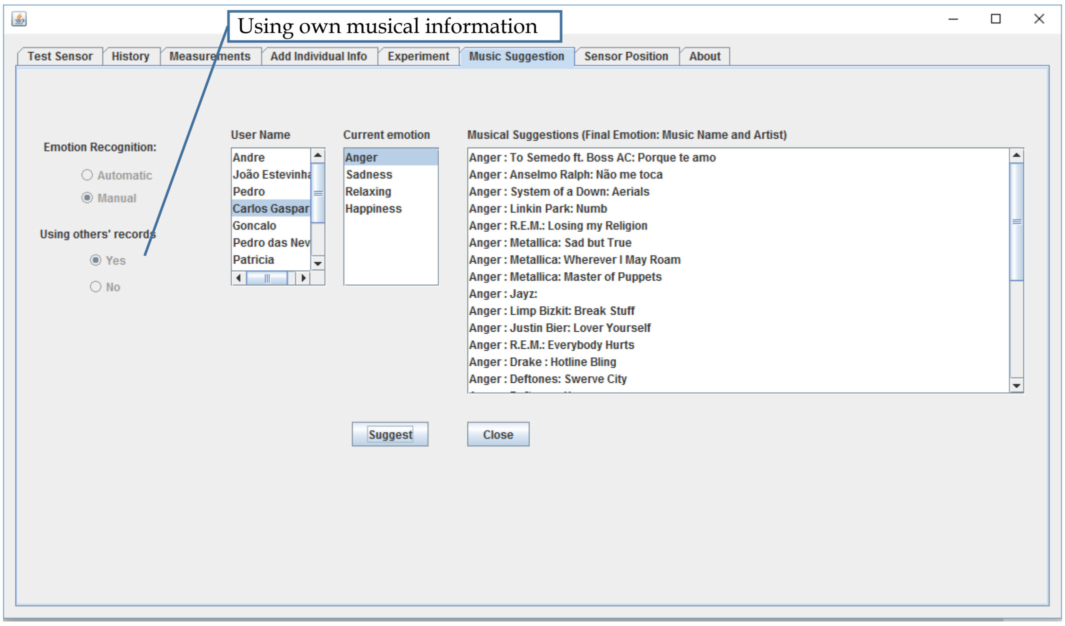


Figure 27 - Music suggestion

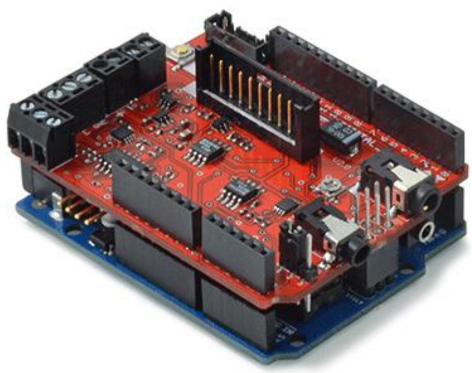
Sensor Positions

Figure 28 - It shows the position as well as information of several sensors and how they

7.2.2. Low Level Guide

A Framework for Profiling based on Music and Physiological State

Manual – Low Level Guide



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Installation guide

I. Java Development Kit 8 (JDK8)

II. NetBeans IDE 8.

This program was responsible for developing the code for the Java program.

III. MySQL (MySQL server, MySQLWorkbench and connector/j).

   a. On MySQLWorkbench it is necessary to create one server with user: “root” and password “123123”. Then it is necessary to create one database called: “datarecordsdb” and use the port number: “3306”.
   On MySQLWorkbench it is also necessary to add the script to create all the necessary tables on the dababase.

   b. On NetBeans, it is added the library of the driver JDBC, which is on the installation folder of the MySqlConnector/j, with the name: “mysql-connector-java-version.jar”.

MySQLWorkbench was used for creating available tables in order to store the physiological measurements.

IV. Protégé 3.5 with Java included. This version of protégé is old and for that reason it only runs with older versions of Java. For that reason, it is easier if this program is installed along with Java.

   a. On NetBeans, it is added the library “protege.jar”, which is located on protege’s parent folder :”…/Protege_3.5/”.

   b. On NetBeans, it is necessary to add all libraries related to protégé in order to use with Java. To do that, it is necessary to add on the project all “.jar” files which are located on “…/Protege_3.5/plugins/edu.stanford.smi.protegex.owl/”.

This program was used to make all relations between all different components of this system. It was also stored all knowledge of this program.

V. Arduino 1.6.4. Although Cooking Hacks (the manufacture of the shield that connects all different sensors) recommended the Arduino 1.0.1 version, it was not identified any problem using the most recent version.

   a. To use the serial communication via RxTx, it is necessary to add the “RXTXcomm.jar” file into the folder :”…/Java/jdk1.8.0.65/jre/lib/ext”. The serial communication doesn’t work if this file isn’t on the JAVA folder.

This program has used for defining which port of the Arduino is available and what information is send through serial communication.

VI. MATLAB 2015-a.

   a. To use all functions made on MATLAB program, it is necessary to compile these functions, which is made with “Application Compiler” tool. After that, the tool creates all necessary libraries with the same functionality of the compiled functions. To use these libraries, it is necessary to add them to the project on NetBeans, which is located on the folder defined by Matlab Application Compiler: “…/for_redistribution_files_only/” and it is the “.jar” file.

This program was used in order to create objects which are responsible for computing the characteristics of the physiological signals. MATLAB was also used to create models based on one machine learning.

The following image illustrates the classpath variables that were defined for the version 1.0 of the program.

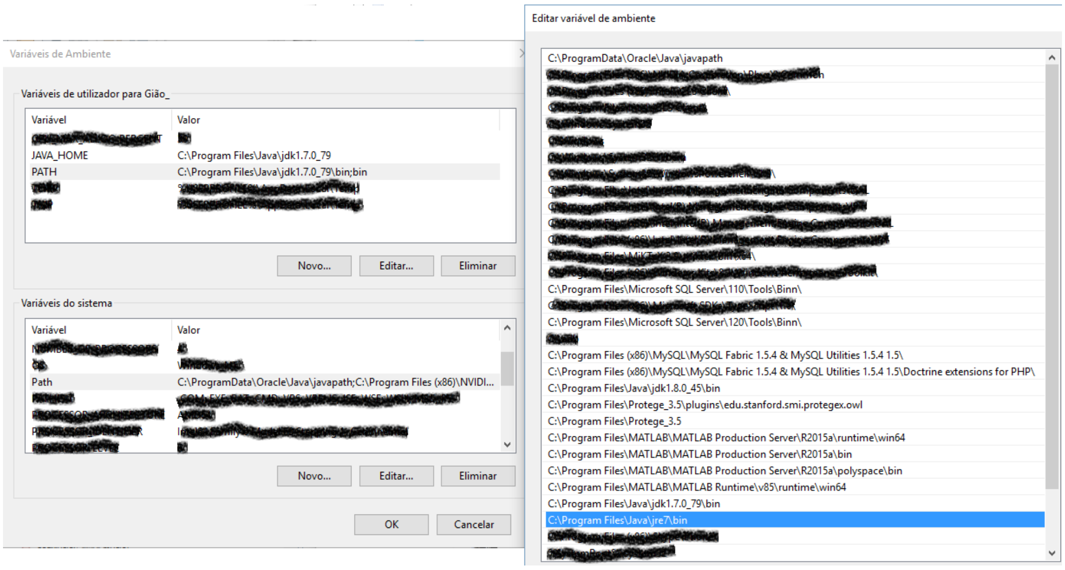

Figure 1 - It shows the installation configuration of environment dependencies

Specifications

MATLAB libraries

All libraries compiled with MATLAB need to be added to the Libraries of the program. To make this, go to “ProjectName” -> Libraries -> Add JAR/Folder and add specify the folded that is the compiled MATLAB program.

DataBase

The path to save the records of the data base as well as all information regarding its connection. This path’s specification is made at: *DataBase*.ConnectDB

Ontology

The path to the ontology “.owl” file is defined at: *Ontology*.JenaBasicFuncions

Arduino

It is defined all specifications of the serial communication at: *Serial*.Communication

Low Level Specifications

DataAnalysis

FeacturesAquired

This class is where is saved the values from the physiological sensors as well as if that sensor was defined, by the user, as active or not.

FeacturesExtractMATLAB

This class computes all physiological characteristics regarding each one of the physiological signals. It was made for one Emotional Record, which as two important moments, the starting measurement and the end of the measurement. The first moment of measurement is where it is defined one initial emotion, and the other moment of measurement is where it is defined one final emotion.

To compute the characteristics, the program uses the libraries compiled with MATLAB, which has separated functions for ECG, Airflow, Common Features and if it is necessary to smooth the signal. For all signals, it is used a limit that is pre-defined as 2000. This value, according to the bibliography, can change between 2000 and 5000 and it is used for making more characteristics for the same period of time.

DataAquired

DataAquired

The object of this class is used for saving, a priori, the values from the Arduino, which are passed through RxTx. It was necessary to have this auxiliary class to save these values because the frequency rate of data is very fast and first the values are stored on Java variables, and when the communication ends, they are putted into the database.

DataEmotionalRecord

This class is to store all information regarding emotional records

DataUser

This class is to store all information regarding each user.

DataBase

ConnectDB

This class is for the high-level functions of the connection with the DataBase. To use this object, first, it is necessary to start one connection, and then this connection is passed it is through function's parameters.

ManagementDB

This class has all queries that are necessary to save, erase and acquire from all physiological measurements, either from .txt files or from one Database.

Images

It has all images used in this program.

Interface

This package has all user's interfaces.

Ontology

JenaBasicFunctions

This class has low-level queries that are used in order to acquire and save all information into the ontology.

JenaMethodology

High-level class that is used as one object by the program in order to perform all tasks related with the ontology.

PlotManagement

JFreeChartUtils

This class uses the information of the dataAquired in order to perform the plots from the physiological measurements. It is a high-level class

PlotFunctions

It has all algorithms to make all the necessary plots. It is a low-level class

Serial

Communication

This class has specifications of the communication between Arduino and Java. It has high-level functions responsible for serial communication. For this communication, it is implemented one Event that is activated when Java receives data from one serial communication. This Event is trigged only when any device sends data from serial communication.

DataTreatment

Low-level functions that are responsible for splinting the serial data for each sensor.

8

8. Bibliography

[1] R. G. Cooper, J. Al-muhtadi, R. Ashford, F. Street, P. Barr, B. Birmingham, I. Sciences, and S. Arabia, "Smart Spaces with Real-Time Physiological Measurement and Mitigation of Stress," in *Pervasive Computing and Applications, 2008. ICPCA 2008. Third International Conference on (Volume:1)*, 2008, pp. 3–8.

[2] Y. L. Ferguson and K. M. Sheldon, "Trying to be happier really can work: Two experimental studies," *J. Posit. Psychol.*, vol. 8, no. 1, pp. 23–33, 2013.

[3] L. M. Camarinha-matos, "Unit 2 : SCIENTIFIC METHOD," *Scientific Research Methodologies and Techniques - Unit 2:Scientific Method*. pp. 1–50, 2012.

[4] J. A. Russell and L. F. Barrett, "Core Affect, Prototypical Emotional Episodes, and Other Things Called Emotion: Dissecting the Elephant," *J. Pers. Soc. Psychol.*, vol. 76, no. 5, pp. 805–819, 1999.

[5] M. Feidakis, T. Daradoumis, and S. Caballé, "A Multi-fold Time Approach to Address Emotions in Live and Virtualized Collaborative Learning," in *Complex, Intelligent and Software Intensive Systems (CISIS), 2012 Sixth International Conference on*, 2012, pp. 881–886.

[6] P. R. Kleinginna and A. M. Kleinginna, "A Categorized List of Emotion Definitions, with Suggestions for a Consensual Definition," *Motiv. Emot.*, vol. 5, no. 4, pp. 345–379, 1981.

[7] P. Adriano and I. Augustin, "A Learning Object Recommendation System: Affective-Recommender," in *Technology Platform Innovations and Forthcoming Trends in Ubiquitous Learning*, IGI Global, Ed. 2013, pp. 254–269.

[8] H. Kennedy, R. Unnithan, and M. Z. Wamboldt, "Assessing Brief Changes in Adolescents' Mood: Development, Validation and Utility of the Fast

Assessment of Children's Emotions (FACE)," *J. Pediatr. Heal. Care*, vol. 29, no. 4, pp. 335–342, 2015.

[9] L. D. Stone and G. a. Thompson, "Classroom mood and the dance of stance: The role of affective and epistemic stancetaking in the development of a classroom mood," *Learn. Cult. Soc. Interact.*, vol. 3, no. 4, pp. 309–322, 2014.

[10] D. Watson, J. Vaidya, J. A. Schinka, and W. F. Velicer, "Mood measurement: Current status and future directions.," in *Handbook of psychology: Research methods in psychology, Vol. 2*, 2003, pp. 351–375.

[11] O. Andrew, C. Gerald L, and C. Allan, "The Cognitive Structure of Emotions," in *Cambridge University Press*, 1990, pp. 18–19.

[12] C. H. C. Leung and J. Deng, "Emotion-Based Music Retrieval," in *Encyclopedia of Information Science and Technology*, vol. 3, IGI Global, 2015, pp. 143–153.

[13] M. A. Nicolaou, H. Gunes, and M. Pantic, "Continuous Prediction of Spontaneous Affect from Multiple Cues and Modalities in Valence-Arousal Space," *IEEE Trans. Affect. Comput.*, vol. 2, no. 2, pp. 92–105, Apr. 2011.

[14] B. Kort and R. Reilly, "Analytical Models of Emotions, Learning and Relationships: Towards an Affect-sensitive Cognitive Machine," in *Proc. of the International Conference on Virtual Worlds and Simulation (VWSim)*, 2002, pp. 1–13.

[15] T. Hascher, "Learning and Emotion: Perspectives for Theory and Research," *Eur. Educ. Res. J.*, vol. 9, no. 1, pp. 13–28, 2010.

[16] J. E. Stets and J. H. Turner, "The Sociology of Emotions," in *Handbook of Emotions*, 3rd ed., The Guilford Press, 2008, p. 35.

[17] O. Alzoubi, S. K. D'Mello, and R. a. Calvo, "Detecting naturalistic expressions of nonbasic affect using physiological signals," *IEEE Trans. Affect. Comput.*, vol. 3, no. 3, pp. 298–310, 2012.

[18] C. Dongwei, W. Fang, W. Zhen, L. Haifang, and C. Junjie, "Eeg-based emotion recognition with brain network using independent components analysis and granger causality," in *Computer Medical Applications (ICCMA), 2013 International Conference on*, 2013, pp. 1–6.

[19] S. Hoseingholizade, M. Reza Hashemi Golpaygani, and A. S. Monfared, "Studying emotion through nonlinear processing of EEG," in *Procedia - Social and Behavioral Sciences*, 2012, vol. 32, pp. 163–169.

[20] T. Wu and S. Jeng, "Probabilistic Estimation of a Novel Music Emotion Model," in *Proceeding MMM'08 Proceedings of the 14th international conference on Advances in multimedia modeling*, 2008, pp. 487–497.

[21] F. Canento, A. Fred, H. Silva, H. Gamboa, and A. Lourenço, "Multimodal biosignal sensor data handling for emotion recognition," in *Sensors, 2011*

IEEE, 2011, pp. 647–650.

[22] "Todos os tipos de sensores," *Saber Eletrônica*, p. Nº405, 2006.

[23] A. M. N. Gomes, "Geração Procedimental baseada em Dados Afetivos," Universidade do Porto, 2014.

[24] J. Kim and E. André, "Emotion recognition based on physiological changes in music listening," *IEEE Trans. Pattern Anal. Mach. Intell.*, vol. 30, no. 12, pp. 2067–2083, 2008.

[25] K. H. Kim, S. W. Bang, and S. R. Kim, "Emotion recognition system using short-term monitoring of physiological signals," *Med. Biol. Eng. Comput.*, vol. 42, no. 3, pp. 419–427, 2004.

[26] "Cooking Hacks: e-Health Sensor Platform V2.0 for Arduino and Raspberry Pi [Biometric/Medical Applications]," 2015. [Online]. Available: https://www.cooking-hacks.com/documentation/tutorials/ehealth-biometric-sensor-platform-arduino-raspberry-pi-medical/. [Accessed: 01-Jul-2015].

[27] W. Sroykham, I. J. Wongsathikun, and Y. Wongsawat, "The effects of perceiving color in living environment on QEEG, oxygen saturation, pulse rate, and emotion regulation in humans," in *Engineering in Medicine and Biology Society (EMBC), 2014 36th Annual International Conference of the IEEE*, 2014, pp. 6226–6229.

[28] W. Wen, G. Liu, N. Cheng, J. Wei, P. Shangguan, and W. Huang, "Emotion Recognition Based on Multi-Variant Correlation of Physiological Signals," *IEEE Trans. Affect. Comput.*, vol. 5, no. 2, pp. 126–140, 2014.

[29] D. Hodges, "Psychophysiological Measures," in *Handbook of Music and Emotion: Theory, Research, Applications*, Oxford, 2012.

[30] K. Revett, "A Biosignal Based Approach," in *Behavioral Biometrics*, IGI Global, 2010, pp. 101–110.

[31] W. Handouzi, C. Maaoui, A. Pruski, and A. Moussaoui, "Objective model assessment for short-term anxiety recognition from blood volume pulse signal," *Biomed. Signal Process. Control*, vol. 14, pp. 217–227, 2014.

[32] R. L. Hazlett, "Measuring Emotional Valence during Interactive Experiences: Boys at Video Game Play," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2006, pp. 1023–1026.

[33] E. L. Van Den Broek, V. Lisý, J. H. Janssen, J. H. D. M. Westerink, M. H. Schut, and K. Tuinenbreijer, "Affective Man-Machine Interface: Unveiling Human Emotions through Biosignals," in *Biomedical Engineering Systems and Technologies*, vol. 52, 2010, pp. 21–47.

[34] R. L. Mandryk and M. S. Atkins, "A fuzzy physiological approach for continuously modeling emotion during interaction with play technologies," *Int. J. Hum. Comput. Stud.*, vol. 65, no. 4, pp. 329–347, 2007.

[35] A. Haag, S. Goronzy, P. Schaich, and J. Williams, “Emotion Recognition Using Bio-sensors: First Steps towards an Automatic System,” in *Lecture Notes in Computer Science*, Springer, Ed. 2004, pp. 36–48.

[36] J. Chen, B. Hu, P. Moore, X. Zhang, and X. Ma, “Electroencephalogram-based emotion assessment system using ontology and data mining techniques,” *Appl. Soft Comput.*, vol. 30, pp. 663–674, 2015.

[37] X. Jia, K. Li, X. Li, and A. Zhang, “A Novel Semi-Supervised Deep Learning Framework for Affective State Recognition on EEG Signals,” in *ioinformatics and Bioengineering (BIBE), 2014 IEEE International Conference on*, 2014, pp. 30–37.

[38] European Commission, “A Guide to ICT-related activities in WP2016-17,” 2015.

[39] “Compound annual growth rate of global music revenue between 2013 and 2018, by category,” *Statistica 2015*. [Online]. Available: http://www.statista.com/statistics/307427/compound-annual-growth-rate-global-music-revenue-by-category/. [Accessed: 23-Nov-2015].

[40] Lei Song, Yongcai Wang, Ji-Jiang Yang, and Jianqiang Li, “Health sensing by wearable sensors and mobile phones: A survey,” in *2014 IEEE 16th International Conference on e-Health Networking, Applications and Services (Healthcom)*, 2014, pp. 453–459.

[41] A. Sano, A. J. Phillips, A. Z. Yu, A. W. Mchill, S. Taylor, N. Jaques, C. A. Czeisler, E. B. Klerman, and R. W. Picard, “Recognizing academic performance, sleep quality, stress level, and mental health using personality traits, wearable sensors and mobile phones,” in *Wearable and Implantable Body Sensor Networks (BSN), 2015 IEEE 12th International Conference on*, 2015, pp. 1–6.

[42] T. Teixeiraa, P. Malo, B. Almeida, and M. Mateus, “Towards an Interoperability Management System,” in *Information Systems and Technologies (CISTI), 2011 6th Iberian Conference on,* 2011, pp. 1–4.

[43] F. Han, E. Moller, and A. J. Berre, “Organizational Interoperability Supported through Goal Alignment with BMM and Service Collaboration with SoaML,” in *Interoperability for Enterprise Software and Applications China, 2009. IESA '09. International Conference on*, 2009, pp. 268–274.

[44] F. Amato, A. R. Fasolino, A. Mazzeo, V. Moscato, A. Picariello, S. Romano, and P. Tramontana, “Ensuring Semantic Interoperability for e-Health Applications,” in *Complex, Intelligent and Software Intensive Systems (CISIS), 2011 International Conference on*, 2011, pp. 315–320.

[45] J. Sarraipa and R. Goncalves, *Knowledge Integration for Semantic Adaptability of Information Systems*. 2013, pp. 1–53.

[46] I. Macía, “Towards a semantic interoperability environment,” in *e-Health*

Networking, Applications and Services (Healthcom), 2014 IEEE 16th International Conference on, 2014, pp. 543–548.

[47] G. Bellinger, D. Castro, and A. Mills, “Data, Information, Knowledge, and Wisdom,” *http://www.systems-thinking.org/dikw/dikw.htm*, 2004. .

[48] P. D. Bamidis, E. Kaldoudi, and C. Pattichis, “From taxonomies to folksonomies: a roadmap from formal to informal modeling of medical concepts and objects,” in *Information Technology and Applications in Biomedicine, 2009. ITAB 2009. 9th International Conference on*, 2009, no. November, pp. 1–4.

[49] J. Salim, S. F. Mohamad Hashim, and S. A. M. Noah, “A framework to the development of Islamic ontology: Symbiosis of thesaurus and domain expert in ontology development,” in *Electrical Engineering and Informatics (ICEEI), 2011 International Conference on*, 2011, p. 16.

[50] C. Hao, “Research on Knowledge Model for Ontology-Based Knowledge Base,” in *Business Computing and Global Informatization (BCGIN), 2011 International Conference on*, 2011, pp. 397–399.

[51] A. Vo, K. Liu, T. Horan, and Y. He, “Toward Global Health Interoperability: Ontology Development of Traditional Chinese Medicine Through Comparative Analyses,” in *System Sciences (HICSS), 2015 48th Hawaii International Conference on*, 2015, pp. 2843–2852.

[52] Y. Yan, J. Zhang, and M. Yan, “Ontology Modeling for Contract: Using OWL to Express Semantic Relations,” in *Enterprise Distributed Object Computing Conference, 2006. EDOC '06. 10th IEEE International*, 2006, pp. 409–412.

[53] N. Kumar and S. Kumar, “Querying RDF and OWL data source using SPARQL,” in *Computing, Communications and Networking Technologies (ICCCNT),2013 Fourth International Conference on*, 2013, pp. 1–6.

[54] J. A. Khan and S. Kumar, “Deep analysis for development of RDF, RDFS and OWL ontologies with protege,” in *Reliability, Infocom Technologies and Optimization (ICRITO) (Trends and Future Directions), 2014 3rd International Conference on* , 2014, pp. 1–6.

[55] MIT, ERCIM, and Keio, “OWL 2 Web Ontology Language Document Overview (Second Edition),” *W3C Recommendation*, 2012. [Online]. Available: http://www.w3.org/TR/owl2-overview/. [Accessed: 01-Oct-2015].

[56] Y. Jing, D. Jeong, and D.-K. Baik, “SPARQL Graph Pattern Rewriting for OWL-DL Inference Query,” in *Networked Computing and Advanced Information Management, 2008. NCM '08. Fourth International Conference on*, 2008, pp. 675–680.

[57] G. Meditskos, S. Dasiopoulou, V. Efstathiou, and I. Kompatsiaris, “SP-

ACT: A hybrid framework for complex activity recognition combining OWL and SPARQL rules," in *Pervasive Computing and Communications Workshops (PERCOM Workshops), 2013 IEEE International Conference on*, 2013, pp. 25–30.

[58] "W3C Semantic Web," *W3C - Semantic Web Standards*, 2014. [Online]. Available: https://www.w3.org/2001/sw/wiki/Main_Page. [Accessed: 01-Oct-2015].

[59] M. Bazzani, D. Conzon, A. Scalera, M. A. Spirito, and C. I. Trainito, "Enabling the IoT paradigm in E-health solutions through the VIRTUS middleware," in *Trust, Security and Privacy in Computing and Communications (TrustCom), 2012 IEEE 11th International Conference on*, 2012, pp. 1954–1959.

[60] L. Gao, M. Bruenig, and J. Hunter, "Estimating Fire Weather Indices via Semantic Reasonong over Wireless Sensor," *Int. J. Web Semant. Technol.*, vol. 5, no. 4, pp. 1 – 20, 2014.

[61] H. Mora-Mora, V. Gilart-Iglesias, D. Gil, and A. Sirvent-Llamas, "A Computational Architecture Based on RFID Sensors for Traceability in Smart Cities," *Sensors*, vol. 15, no. 6, pp. 13591–13626, 2015.

[62] J. Wei, "How Wearables Intersect with the Cloud and the Internet of Things : Considerations for the developers of wearables," *IEEE Consum. Electron. Mag.*, vol. 3, no. 3, pp. 53–56, 2014.

[63] S. Kirk, "The wearables revolution: Is standardization a help or a hindrance? Mainstream technology or just a passing phase?," *IEEE Consum. Electron. Mag.*, vol. 3, no. 4, pp. 45–50, 2014.

[64] T. Components, S. T. Services, and T. Information, "Datasheet - YSI Precision Thermistors & Probes Thermistors at YSI."

[65] G. D. Clifford, "ECG statistics, noise, artifacts, and missing data," in *Advanced Methods and Tools for ECG Data Analysis*, 2006, pp. 55–99.

[66] G. Chanel, K. Ansari-Asl, and T. Pun, "Valence-arousal evaluation using physiological signals in an emotion recall paradigm," in *Systems, Man and Cybernetics, 2007. ISIC. IEEE International Conference on*, 2007, vol. 41, no. 22, pp. 2662–2667.

[67] "Apache Jena," 2015. [Online]. Available: https://jena.apache.org/index.html. [Accessed: 01-Oct-2015].

[68] "MySQL." [Online]. Available: http://www.mysql.com/.

[69] "Netbeans IDE." [Online]. Available: https://netbeans.org/.

[70] T. N. C. for B. Ontology., "Protégé." [Online]. Available: http://protege.stanford.edu/.

[71] "MathWorks - Matlab." [Online]. Available:

http://www.mathworks.com/.

[72] K. Takahashi, S. Y. Namikawa, and M. Hashimoto, "Computational emotion recognition using multimodal physiological signals: Elicited using Japanese kanji words," in *Telecommunications and Signal Processing (TSP), 2012 35th International Conference on*, 2012, pp. 615–620.

[73] R. W. Picard, E. Vyzas, and J. Healey, "Toward Machine Emotional Intelligence: Analysis of Affective Physiological State," *Pattern Anal. Mach. Intell. IEEE Trans.*, vol. 23, no. 10, pp. 1175–1191, 2001.

[74] J. A. Healey, "Wearable and Automotive Systems for Affect Recognition from Physiology," Massachusetts Institute of Technology, 2000.

[75] X. L. Wang, J. M. E. Smieee, and C. M. Smieee, "Parametric Power Spectrum Analysis of ECG Signals for Obstructive Sleep Apnoea Classification," in *Computer-Based Medical Systems (CBMS), 2014 IEEE 27th International Symposium on*, 2014, pp. 8–13.

[76] "Spectral Analysis of Signals with Unevenly Spaced Samples," *MATLAB Examples*. [Online]. Available: http://www.mathworks.com/examples/signal/mw/signal_product-LombPeriodogramExample-spectral-analysis-of-nonuniformly-sampled-signals. [Accessed: 11-Jan-2016].

[77] S. Saha, S. Datta, A. Konar, and R. Janarthanan, "A study on emotion recognition from body gestures using Kinect sensor," in *Communications and Signal Processing (ICCSP), 2014 International Conference on*, 2014, pp. 56–60.

[78] W. Wang and W. Ding, "Research of improved SVM model based on GA in E-learning emotion classification," in *Proceedings - 2012 IEEE 2nd International Conference on Cloud Computing and Intelligence Systems, IEEE CCIS 2012*, 2013, vol. 2, pp. 919–923.

[79] S. Song, M. Kim, S. Rho, and E. Hwang, "Music ontology for mood and situation reasoning to support music retrieval and recommendation," in *Digital Society, 2009. ICDS '09. Third International Conference on*, 2009, pp. 304–309.

[80] D. B. Smith, "Plutchik's Eight Primary Emotions And How To Use Them (Part 1 of 2)," 2010. [Online]. Available: https://dragonscanbebeaten.wordpress.com/2010/06/04/plutchiks-eight-primary-emotions-and-how-to-use-them-part-1/.

[81] "Global mobile audio streaming traffic from 2014 to 2019 (in terabytes per month)," *Statistica 2015*. [Online]. Available: http://www.statista.com/statistics/383731/global-mobile-audio-streaming-traffic/. [Accessed: 23-Nov-2015].

[82] "Digital share of overall music sales in selected countries from 2004 to

2014," *Statistica 2015*. [Online]. Available: http://www.statista.com/statistics/276891/digital-share-of-overall-music-sales-in-selected-countries/. [Accessed: 23-Nov-2015].